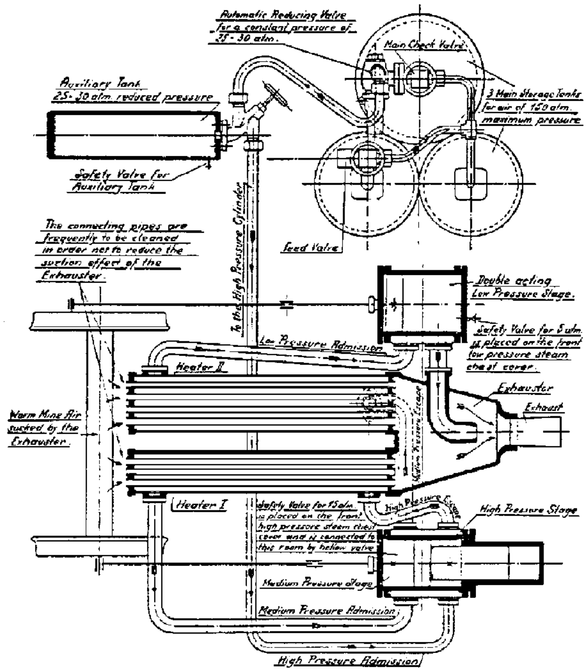
THE AIR ENGINE THAT GOT AIR ENGINES COVERED UP

CONTENTS

1. Heat-power engineering of air engines; Tesla on solar air engine; other inventors using ambient heat as power source 1
2. Charles B. Hodges' patents for the compound air engine 22
3. The heat pump concept (explains overunity); loss of ozone; no-freon refrigerator 51



Automatic Reducing Valve for a constant pressure of 25 - 30 atm.
Main Check Valve
Auxiliary Tank 25-30 atm. reduced pressure
3 Main Storage Tanks for air of 150 atm. maximum pressure
Safety Valve for Auxiliary Tank
To the High Pressure Cylinder
Feed Valve
The connecting pipes are frequently to be cleaned in order not to reduce the suction effect of the Exhauster.
Double acting Low Pressure Stage.
Safety Valve for 5 atm. is placed on the front low pressure steam chest cover.
Low Pressure Admission
Heater II
Exhauster
Exhaust
Warm Mine Air sucked by the Exhauster.
Medium Pressure Escape
Heater I
Safety Valve for 15 atm. is placed on the front high pressure steam chest cover and is connected to this room by hollow valve
High Pressure Escape
High Pressure Stage
Medium Pressure Stage
Medium Pressure Admission
High Pressure Admission

Fig. 3.—Explanatory Diagram of Triple-expansion Compressed-air Locomotive with Double Intermediate Heating.

THE DRAWING ABOVE REPRESENTS THE MOST EFFICIENT AIR ENGINE EVER BUILT, BASED ON PATENTS REPRODUCED IN THIS BOOK

PNEUMATIC OPTIONS RESEARCH LIBRARY www.AirCarAccess.com

Was Tesla the true inventor of the solar air engine?

During the last two decades of the 19th century, while the fledgling compressed air locomotive industry struggled to gain a foothold in the face of competition from steam, electricity, gasoline and its own inadequacies, Nikola Tesla was quietly working to invent the means whereby the compressed air engine could be made self-fueling, powered by ambient heat, constantly replenished by the sun.

Tesla knew about the second law of thermodynamics, which states that energy goes from a concentrated, usable form, to a dissipated, less usable form. He disagreed, not with the law itself, but with interpretations of the law which claim that it's virtually impossible for a machine to cool a portion of its environment below ambient temperature in order to draw heat-as-fuel into itself, to make itself totally self-fueling. In order to prove that an engine could run on nothing but solar-induced ambient heat, Tesla invented his mechanical oscillator, a reciprocating piston engine with no piston rings, lubrication or valves. By eliminating most of the air engine's moving parts, thereby most of its friction losses, Tesla hoped to give his theory its best chance of working in practice. He then invented a compressor similar in concept to his oscillating engine, eliminating all rotary motion from the resulting air engine/compressor assembly. Despite the high efficiency of a machine having so few moving parts, this would have been a perpetual motion idea if he'd stopped there. But the engine and compressor were only the first two parts of his five-part plan for a self-fueling solar pneumatic engine.

In the spring of 1895, Tesla was working on the third part of the solar power plant, which he doesn't fully describe in the article I've seen, but its function was to produce refrigeration in a very simple and efficient way. Then his laboratory burned down, and he was never able to finish his invention, though he firmly believed that it would work.

In an article published in Century Magazine in June, 1900, Tesla revealed for the first time that his real purpose for inventing the oscillating engine--which he also used as an actuator to generate electricity--was to provide the world with a solar power plant that would run on compressed air and ambient heat. In 1986 I coincidentally got on the same theme of entraining ambient heat for a self-fueling pneumatic power plant, not knowing of Tesla's work in this field. I even chose for my design the oscillating engine Tesla had invented for this express purpose.

Two years after Tesla revealed that his oscillator was meant to be part of a solar power plant, Edward A. Rix of San Francisco published an article in a technical journal about using three-stage air engines to pump water. This is the first and last reference I've ever seen to triple expansion air engines being used in the U.S. Rix gives the results of reheating the cold air between stages with the ambient heat in the water that the engine is pumping. This is basically a groundwater-source heat pump supplying an air engine with a good chunk of its fuel supply for free. Edward Rix was one of the pioneers of modern pneumatics, and the compressor company he founded is worth over $5 million today. Rix built pneumatic locomotives, published textbooks and articles on the use of compressed air, and received many patents on pneumatic power machinery.

Until early in this century, an air engine would use air expansively to push one piston and then exhaust the air. Because of the large drop in temperature accompanying its expansion, the air had to be reheated before it could be admitted to the engine, to keep the engine from freezing up. The primary fuel for this reheating was coal which was usually burned to heat water at the filling station. The locomotive would fill up with hot water when it stopped to fill up with air.

In 1904, J.F. Gairns published an article describing the virtues of the Vauclain compound locomotive built for the Philadelphia and Reading Coal and Iron Co. This system, and the H.K. Porter Co.'s system that C. B. Hodges wrote about in 1905, used ribbed cylinders to absorb as much ambient heat as possible to reheat the air.

In 1904, four years after Tesla published his revelation about ambient heat as a fuel source, the same Charles Bowen Hodges of Pittsburgh invented the "atmospheric interheater", which I call the ambient heater. This simple heat exchanger is placed between the stages in a two-stage air engine. The air exhausted from the first-stage cylinder into the interheater is extremely cold and absorbs ambient heat in the interheater before being used again to push the second-stage piston. Thus was eliminated the need to burn coal for the reheating of compressed air in engines.

The compressed air locomotive industry jumped on this idea and adopted it across-the-board, beginning in 1907 when Hodges got his patent. From then on, writers on compressed air locomotives focused on the advantages of ambient heat above all other means for reheating compressed air, and the substantial gain in fuel economy resulting from doing so. Hodges got six or seven more patents between 1908 and 1912 for means of using the interheater in compound compressed air locomotives, all of which he assigned to the H.K. Porter locomotive company. From then on, the H.K. Porter Co. seemed to be almost monopolizing a thriving market for compound compressed air locomotives, which were mainly used in mining. The ambient heat resulted in a 30% reduction of fuel consumption by the air engine. This is analogous to modifying a gasoline engine that normally gets 30 mpg, in such a way that it gets about 40 mpg.

By 1910, the compound pneumatic locomotive was being used in Britain. Two years later the Europeans took the pneumatic/ambient heat engine two steps further than the Americans would ever take it, by building triple expansion air engines for their mine locomotives. These engines absorbed ambient heat before all three stages, using three ambient heaters to the Americans' one, and consumed 55% less compressed air than they would have without the ambient heat. This is analogous to a gasoline engine that normally gets 30 mpg, modified to get almost 50 mpg. Triple expansion pneumatic locomotives were used in Britain, France, Germany, Spain, Austria-Hungary, and Belgium. While hundreds of H.K. Porter two-stage locomotives were hauling coal in the U.S., there were hundreds of A. Borsig Co. three-stage locomotives hauling coal in Germany alone.

In July of 1914, the war with Germany began.

In August of 1914, the editor of the Compressed Air Magazine published a disclaimer for his magazine's June article on the triple-expansion pneumatic locomotives being used in Europe. The article offers no technical arguments, but in a sarcastic, pro-American vein, thrashes out at the idea that triple expansion engines could possibly be as efficient as everybody else was saying they were. Citing no technical evidence whatsoever, but only raving in a jingoistic fashion, the editor failed to impress anybody and the use of compound pneumatic locomotives continued throughout the 1920's in the U.S. and Europe. Detailed studies on the air consumption of triple expansion pneumatic locomotives used in France were published in the early 1920's. Successive editions of Robert Peele's widely-used compressed air and mining textbooks continued to emphasize the importance of ambient heat.

I assume that it was the Depression and the Second World War that brought the thriving market for pneumatic/ambient heat engines to a halt in the 1930's.

Whether Nikola Tesla was actually the original source of inspiration for the solar pneumatic engine isn't important, but one more bit of circumstantial evidence should be included here. Sometime after 1910, Tesla formed the Tesla Propulsion Co. in Albany, New York, to develop his steam- or compressed air-powered bladeless turbine for ships and the coal mining industry. In this venture, Tesla's partners were Joseph Hoadley and Walter H. Knight, inventors of the highly successful Hoadley-Knight pneumatic locomotives used for street transit. Hoadley-Knight engines were compound, but still used hot water from filling stations to reheat the air, instead of ambient heaters.

I'd appreciate hearing from anyone who knows of a more complete source of information on Tesla's five-part plan for fueling a solar pneumatic power plant with ambient heat.

"I expect to live to be able to set a machine in the middle of this room and move it by no other agency than the energy of the medium in motion around us." --Nikola Tesla, New York Times, September 30, 1894. (At the time he made the above statement, Tesla was, in his words, "pushing vigorously" toward the completion of the linear air engine/compressor that made up the first two parts of his five-part solar pneumatic power plant. His term for ambient heat was "the energy in the ambient medium," almost exactly the same term he used to refer to the fuel source for the self-acting machine he named in the above quote. In 1894 he was keeping it a secret what his ambient energy source was, not revealing till 1900 that it was heat stored in the atmosphere by solar radiation. The above quote has often been assumed to be in reference to some sort of electromagnetic free energy device, but I suspect that this famous quote is actually referring directly to Tesla's then-current experiments on running engines on compressed air and ambient heat.)

Luther Kangley
June 1, 1987

THE MOTHER EARTH NEWS®

NOVEMBER/DECEMBER 1977

> *Soft technologies are diverse . . . rely on renewable energy flows . . . are understandable . . . and are matched in scale and energy quality to end-use needs.*

PLOWBOY: Perhaps you could explain what you mean by that . . . by matching "energy quality" to end-use needs. What does that mean?

LOVINS: Well as you know, energy comes in many different forms, some of which are what a scientist would call "low grade" energy. That isn't a derogatory term . . . it just means that the kind of energy in question—low-temperature heat, usually—can't do difficult kinds of work. Now, there's an awful lot of low-grade energy around. There's more low-grade energy in the Atlantic Ocean, for instance, than there is high-grade energy in all the oil in the Middle East, but you can't do much with it.

By matching energy quality to end use needs, I simply mean that where you have a job that can be done by low-grade energy, you should use low-grade energy to do that job, and not high-grade energy.

PLOWBOY: Is there much of a need for low-grade energy in this country?

LOVINS: Oh yes. About half of all the energy needed in the U.S. today is required in the form of heat at temperatures below a few hundred degrees Celsius. Altogether something like 58% of our end-use needs are for heat. And only a fraction of that 58% is high-temperature heat.

PLOWBOY: How do you answer critics who say that energy storage is a major problem with soft technologies?

LOVINS: I think they've got it backwards. Energy storage is a major problem with hard technologies. It's a minor problem with soft technologies. The reason for this is that with soft technologies, you aren't trying to electrify everything or store large amounts of energy. You would instead be trying—where you needed storage—to store energy at the point of end use, in rather small amounts, and often at rather low quality. Now it's very simple to store low-temperature heat . . . you can do it in water or rocks. There might be more elegant ways to do it, but you don't need them.

Again, let's go through the kinds of energy we're talking about. Low- and high-temperature heat would be stored *as heat*, at the point of end use. That's easy. Liquid fuels would be stored as liquid fuels. That's easy . . . we're already doing it. Electricity would be stored as water behind existing dams. We're already doing that too. That's all there is, except maybe for mechanical energy, which you can always store as compressed air.

PLOWBOY: Compressed air? That's not very practical, is it?

LOVINS: I think it is. Some European cities—Paris and Vienna, for example—used to offer compressed air as a standard utility. It ran all the motors in those towns until the turn of the century, when electricity took over. Compressed air is actually a very highly developed technology. I recently looked in the Yellow Pages of the phone book in a large American city, under the heading "Compressed Air", and there were something like six pages of listings!

Compressed air is very handy stuff. It's exceedingly simple and reliable. It's spark-proof, which—of course—is why it's used so much in mining. And it has good torqueing characteristics . . . air-powered wrenches are used, for example, in car assembly. Of course, it's also used there because if the workers were to steal the tools and take them home, they wouldn't be able to use them.

Anyway, I think compressed air has been much underrated as an energy carrier.

Rocky Mountain Institute Newsletter

Amory Lovins (Director of Research), a consultant experimental physicist, was educated at Harvard and Oxford. He holds an Oxford MA and five honorary doctorates, has taught at many universities, and has been active in energy policy in more than 15 countries. A Fellow of the American Association for the Advancement of Science and former member of the Department of Energy's senior advisory board, he has published a dozen books and over 100 papers. His energy consultancy to many national, state, and local governments and to private firms has made him, in *Newsweek's* terms, "one of the Western world's most influential energy thinkers." He and Hunter shared a 1982 Mitchell Prize and a 1983 Right Livelihood Award (often called the " alternative Nobel Prize").

[photos by Doug Child]

HEAT-POWER ENGINEERING

BY

WILLIAM N. BARNARD, M.E.
Professor of Power Engineering, Cornell University

FRANK O. ELLENWOOD, A.B., M.E.
Professor of Power Engineering, Cornell University

CLARENCE F. HIRSHFELD, M.M.E.
Chief, Research Department, The Detroit Edison Co.
Formerly Professor of Power Engineering, Cornell University

THIRD EDITION 1926

113. The Air Engine.—(a) Compressed air is used commercially in many different ways but most widely in engines for the production of power, the air serving as the working substance. At first sight it seems an uneconomical method of producing power as the air compressor must be driven by an engine or motor of some sort which apparently might better be used directly to produce the power desired, rather than to suffer the additional losses incurred in a compressor and in utilization of the compressed air in a second engine.

(b) Such reasoning is generally sound for conditions where the desired power can be conveniently generated at the point of utilization by a prime mover. There are, however, many cases where this cannot be done. Where a number of small engines are to be operated at widely scattered points and where electrical motors are not suitable, compressed air engines find a field to which they are admirably suited. Compressed air can easily be transmitted over great distances without serious loss. Steam, on the other hand, cannot be efficiently transmitted very far because of the resulting condensation; and more than this, steam engines of small size are very inefficient, and the high temperature at which they operate renders them unsuitable when handling is required. The working substance of internal combustion engines can be transmitted as easily, if not more easily, than compressed air, but the complicated valve and ignition mechanisms, the high temperature and the hot noxious exhaust gases make them less desirable than compressed air engines for a number of purposes. Compressed air is more suitable for many kinds of work with small motors than is electricity, because the air can be conveyed by pipe or hose over all sorts of construction work with a minimum amount of labor and expense and with no danger from fire.

(c) Thus, compressed air engines are widely used in mining and quarrying operations and for the driving of small portable tools in shops and such. In Paris there is installed a central compressor station which distributes compressed air, much as gas is distributed in this country, and air is used by the consumers for operating small plants just as electricity is used here.

(d) The indicator diagram of an ideal air engine, which is without clearance and is provided with sufficient piston displacement to allow the *complete expansion* of the air, is shown by Fig. 70. During the period *1–2*, high pressure air is admitted from the pipe line to the cylinder. During *2–3*, the weight of air so admitted is allowed to expand, according to the law $PV^n = a$ *constant*, to atmospheric pressure, p_3. Then the return stroke of the piston exhausts the air from the cylinder, at constant pressure, according to the process *3–4*.

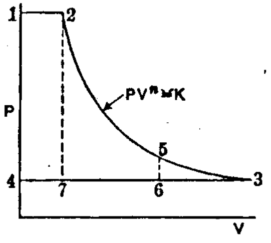


Fig. 70.

The enclosed area *1 2 3 4* measures the net work done upon the piston, during the engine cycle, by the weight of air involved. Summing up the work done by the air during the processes of the cycle, this net work amounts to

$$Wk_{1234} = P_2V_2 + \frac{P_2V_2 - P_3V_3}{n-1} - P_3V_3$$

$$= \frac{n}{n-1} w_2RT_2\left[1 - \left(\frac{p_3}{p_2}\right)^{\frac{n-1}{n}}\right]. \quad . \quad . \quad (145)$$

(e) Although air turbines, or turbine tools, may permit the complete expansion of the air, reciprocating engines are designed for incomplete expansion, or for no expansion whatever. *Incomplete expansion* would be represented by the indicator diagram *12564* in Fig. 70. It is obvious that, for the same weight of air admitted, the net work done per cycle is less, by an amount represented by the area *5 3 6*, than if the air had expanded completely. However, the piston displacement is reduced from V_3 to V_6 and the resulting reduction in frictional losses in the actual engine will counter-balance to some extent the net work that is lost due to the incomplete expansion. Another factor in favor of the incomplete expansion is the reduced cost of the machine due to the reduced piston displacement. Again referring to Fig. 70, it is evident that the net work *done by the air* per cycle amounts to

$$Wk_{12564} = P_2V_2 + \frac{P_2V_2 - P_5V_5}{n-1} - P_6V_6. \quad . \quad . \quad (146)$$

(f) An engine whose indicator diagram is represented by the area *1 2 7 4* in Fig. 70 obviously makes no use whatever of the expansion of the air within the cylinder and operates on the *non-expansion* cycle.

Such an engine, or tool, is characterized by very poor economy in the use of the air supplied, but has the advantage of developing the maximum power per unit of piston displacement and of weight. The net work of this cycle is, as seen from Fig. 70,

$$Wk_{1274} = (P_2 - P_7)V_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad (147)$$

(g) One of the most important applications of compressed air is found in air tools, such as chipping hammers, riveters, drills, etc. They usually operate on the *non-expansion* cycle because they must be of relatively light weight and portable, cheap in first cost, and simple in construction. Their small size and intermittent operation also reduces the necessity for high economy. The other cycles of operation are important, however, because economy is an important item in some services in which the air consumption is steady and of considerable magnitude.

(h) In practice, the air generally enters an engine at about atmospheric temperature, and during the actual expansion it becomes cooled, in some cases to such an extent that the moisture in it freezes and leads to difficulties. The temperature decrease in any real engine will not be equal to the adiabatic, because heat will be supplied to the engine cylinder from the surrounding atmosphere and will tend to make the expansion somewhat more nearly isothermal. If the engine could be operated with extreme slowness the expansion would very closely approach a true isothermal.

(i) This approach toward isothermal expansion is advantageous, when using air at about atmospheric temperature, for the following reasons:

(1) It tends to prevent the deposition, in the form of ice, of the moisture accompanying the air, thus tending to prevent the resultant troubles with lubrication and stoppage of valves and passages.

(2) It increases the work made available, as the area under an isothermal expansion is greater than that under the steeper adiabatic between the same two pressures.

(3) It increases the mechanical efficiency of the engine by keeping the lubricating oil at a higher temperature.

(4) It reduces by a very small amount the weight of air required per cycle as there is less tendency to cool the entering air.

(5) It permits the use of a slightly smaller machine for the same output.

(j) It is interesting to note that, from the viewpoint of the conservation of energy, isothermal operation is not as advantageous as adiabatic. The object of using the air expansively is to utilize some of the internal energy of the working substance which enters the engine. If the expansion is isothermal no work can be done at the expense of such energy; on the contrary, heat equivalent in quantity to the work done during the expansion period must be supplied from an external source. With an adiabatic expansion, however, all of the work done during such an expansion will be at the expense of the *internal* energy of the gas.

The apparent discrepancy between these two cases is due to the fact that during the isothermal expansion it is assumed that the required amount of heat is supplied from the atmosphere, and that it costs nothing, and may, therefore, be freely used without decreasing the commercial efficiency of the process.

(k) Air engines are found to operate more quietly, and therefore more satisfactorily, when the exhaust valve closes before the end of the stroke, thus trapping some air which is then compressed into the clearance. Such operation causes a loss of diagram area and therefore a loss of work from a given size of cylinder running at a given speed. It may, however, result in a saving in two ways in the amount of air used per horsepower hour:

(1) When compression is not used, the air admitted must first be mixed with that in the clearance until the full admission pressure is attained; after that, the entering air becomes available for driving the piston.

(2) Compression tends to raise the temperature of the walls, cylinder head and piston and thus to decrease the cooling effect upon the incoming air.

114. Preheating.—(a) In most cases, compressed air engines and the compressors supplying the working fluid are generally widely separated. It has already been shown that so far as the *compressor* is concerned the cooler the air the better. A cool supply means a larger capacity for a given machine and efficient cooling during operation means a smaller amount of work required. Cool air is also advantageous for the "receiver," or storage tank, and for the pipe line carrying the air to the engine, since the cooler the air the smaller can these parts be for a given weight of air.

(b) Conditions are, however, quite different so far as the *engine* is concerned. The warmer the air, within reason, the better.

If the compressed air could be heated at constant pressure before entering the engine, it would expand according to Charles' law. A given volume of heated air admitted to the engine would represent a smaller actual weight, but would be able to deliver the same amount of work as a larger weight of colder air, and there would be the added advantage that there would be less danger of the moisture freezing at the end of expansion; also the friction losses in the reciprocating air engine will be considerably reduced because of the higher temperature of the cylinder oil.

(c) Such heating of the air is known as "preheating" and the devices in which it is effected are called "preheaters." It is actually used in places where the transmission piping is of great length and also where the engine units are few and of large size. It is found in practice that the running expense for the fuel supplied for preheating is less than the extra charges against the larger compressor and pipe line which would otherwise be used.

115. Air Turbine Tools.—Recently there has been developed a line of compressed air tools operated by air turbines, instead of by reciprocating engines. They are particularly well suited for applications requiring high rotative speed, such as drills, or grinders. They possess the advantage of light weight, simplicity and no vibration. Furthermore, their air consumption is relatively low, due to the fact that the air is used expansively in the nozzle, even though the turbine may be a very small one, such as would be used for small tools. After long use these turbines may have the same air consumption as originally, since the wear does not affect the parts between which leakage may occur.

116. Performance of Air Compressors.—(a) For reciprocating compressors the indicator diagram taken from any actual machine enables the indicated horsepower to be obtained when the compressor is handling a known amount of air, usually measured in terms of the volume of free air per minute. The horsepower calculated for this same amount of air, with isothermal compression, and for constant suction and delivery pressures, is called the *isothermal horsepower*. The ratio of the isothermal horsepower to the actual indicated horsepower is commonly designated as the *efficiency of compression*, or *compression efficiency*. Clearly the compression efficiency will be decreased by leakage and inefficient cooling.

(b) The *mechanical efficiency* of the compressor is the ratio of the i.h.p. of the air cylinders to the horsepower required to drive it. The air i.h.p. includes the power used in overcoming the *fluid friction* due to the resistance of valves and passages. The power needed to drive the compressor exceeds the air i.h.p. by the amount absorbed in *mechanical friction*.

(c) The product of the mechanical efficiency and the compression efficiency gives the true measure of the performance of the compressor and may therefore very properly be called the *compressor efficiency*.

(d) The *overall efficiency*, or the *overall isothermal efficiency*, is the term that most owners of compressors are usually interested in, because it represents the ratio of the isothermal horsepower of the compressor to the horsepower supplied by the engine, turbine, or motor used to drive the machine. This term includes all mechanical losses in the mechanism used for transmitting this power to the compressor.[4] In the case of the steam-driven reciprocating compressor it has been common practice to take the i.hp. of the steam cylinders as the input to the compressor, whereas, strictly speaking, the mechanical losses of the steam end should be deducted in order to obtain the true input to the compressor.

(e) The *overall adiabatic efficiency* is sometimes used as a standard when comparing the performances of compressors, especially centrifugal ones. The term has the same meaning as the one defined in the previous paragraph except that the air horsepower is calculated for *adiabatic* compression instead of isothermal.

(f) An indication of the magnitude of the losses occurring in a modern centrifugal air compressor is shown in Plate V of the Appendix. The American Society of Mechanical Engineers' Test Code for Displacement Compressors and Blowers, and the Code for Centrifugal and Turbo Compressors, are recommended for use when commercial tests are involved.

---

[4] If this mechanism could have an efficiency of 100 per cent the *overall efficiency* would then equal the *compressor efficiency*.

THE PROBLEM OF INCREASING HUMAN ENERGY.

WITH SPECIAL REFERENCE TO THE HARNESSING OF THE SUN'S ENERGY.

BY NIKOLA TESLA.

Century Illustrated Magazine, June 1900

ENERGY FROM THE MEDIUM—THE WINDMILL AND THE SOLAR ENGINE—MOTIVE POWER FROM TERRESTRIAL HEAT—ELECTRICITY FROM NATURAL SOURCES.

But, whatever our resources of primary energy may be in the future, we must, to be rational, obtain it without consumption of any material. Long ago I came to this conclusion, and to arrive at this result only two ways, as before indicated, appeared possible—either to turn to use the energy of the sun stored in the ambient medium, or to transmit, through the medium, the sun's energy to distant places from some locality where it was obtainable without consumption of material. At that time I at once rejected the latter method as entirely impracticable, and turned to examine the possibilities of the former.

It is difficult to believe, but it is, nevertheless, a fact, that since time immemorial man has had at his disposal a fairly good machine which has enabled him to utilize the energy of the ambient medium. This machine is the windmill. Contrary to popular belief, the power obtainable from wind is very considerable. Many a deluded inventor has spent years of his life in endeavoring to "harness the tides," and some have even proposed to compress air by tide- or wave-power for supplying energy, never understanding the signs of the old windmill on the hill, as it sorrowfully waved its arms about and bade them stop. The fact is that a wave- or tide-motor would have, as a rule, but a small chance of competing commercially with the windmill, which is by far the better machine, allowing a much greater amount of energy to be obtained in a simpler way. Wind-power has been, in old times, of inestimable value to man, if for nothing else but for enabling him to cross the seas, and it is even now a very important factor in travel and transportation. But there are great limitations in this ideally simple method of utilizing the sun's energy. The machines are large for a given output, and the power is intermittent, thus necessitating the storage of energy and increasing the cost of the plant.

A far better way, however, to obtain power would be to avail ourselves of the sun's rays, which beat the earth incessantly and supply energy at a maximum rate of over four million horse-power per square mile. Although the average energy received per square mile in any locality during the year is only a small fraction of that amount, yet an inexhaustible source of power would be opened up by the discovery of some efficient method of utilizing the energy of the rays. The only rational way known to me at the time when I began the study of this subject was to employ some kind of heat- or thermodynamic engine, driven by a volatile fluid evaporated in a boiler by the heat of the rays. But closer investigation of this method, and calculation, showed that, notwithstanding the apparently vast amount of energy received from the sun's rays, only a small fraction of that energy could be actually utilized in this manner. Furthermore, the energy supplied through the sun's radiations is periodical, and the same limitations as in the use of the windmill I found to exist here also. After a long study of this mode of obtaining motive power from the sun, taking into account the necessarily large bulk of the boiler, the low efficiency of the heat-engine, the additional cost of storing the energy, and other drawbacks, I came to the conclusion that the "solar engine," a few instances excepted, could not be industrially exploited with success.

A DEPARTURE FROM KNOWN METHODS—POSSIBILITY OF A "SELF-ACTING" ENGINE OR MACHINE, INANIMATE, YET CAPABLE, LIKE A LIVING BEING, OF DERIVING ENERGY FROM THE MEDIUM—THE IDEAL WAY OF OBTAINING MOTIVE POWER.

WHEN I began the investigation of the subject under consideration, and when the preceding or similar ideas presented themselves to me for the first time, though I was then unacquainted with a number of the facts mentioned, a survey of the various ways of utilizing the energy of the medium convinced me, nevertheless, that to arrive at a thoroughly satisfactory practical solution a radical departure from the methods then known had to be made. The windmill, the solar engine, the engine driven by terrestrial heat, had their limitations in the amount of power obtainable. Some new way had to be discovered which would enable us to get more energy. There was enough heat-energy in the medium, but only a small part of it was available for the operation of an engine in the ways then known. Besides, the energy was obtainable only at a very slow rate. Clearly, then, the problem was to discover some new method which would make it possible both to utilize more of the heat-energy of the medium and also to draw it away from the same at a more rapid rate.

I was vainly endeavoring to form an idea of how this might be accomplished, when I read some statements from Carnot and Lord Kelvin (then Sir William Thomson) which meant virtually that it is impossible for an inanimate mechanism or self-acting machine to cool a portion of the medium below the temperature of the surrounding, and operate by the heat abstracted. These statements interested me intensely. Evidently a living being could do this very thing, and since the experiences of my early life which I have related had convinced me that a living being is only an automaton, or, otherwise stated, a "self-acting engine," I came to the conclusion that it was possible to construct a machine which would do the same. As the first step toward this realization I conceived the following mechanism. Imagine a thermopile consisting of a number of bars of metal extending from the earth to the outer space beyond the atmosphere. The heat from below, conducted upward along these metal bars, would cool the earth or the sea or the air, according to the location of the lower parts of the bars, and the result, as is well known, would be an electric current circulating in these bars. The two terminals of the thermopile could now be joined through an electric motor, and, theoretically, this motor would run on and on, until the media below would be cooled down to the temperature of the outer space. This would be an inanimate engine which, to all evidence, would be cooling a portion of the medium below the temperature of the surrounding, and operating by the heat abstracted.

But was it not possible to realize a similar condition without necessarily going to a height? Conceive, for the sake of illustration, an inclosure *T*, as illustrated in diagram *b*, such that energy could not be transferred across it except through a channel or path *O*, and that, by some means or other, in this inclosure a medium were maintained which would have little energy, and that on the outer side of the same there would be the ordinary ambient medium with much energy. Under these assumptions the energy would flow through the path *O*, as indicated by the arrow, and might then be converted on its passage into some other form of energy. The question was, Could such a condition be attained? Could we produce artificially such a "sink" for the energy of the ambient medium to flow in? Suppose that an extremely low temperature could be maintained by some process in a given space; the surrounding medium would then be compelled to give off heat, which could be converted into mechanical or other form of energy, and utilized. By realizing such a plan, we should be enabled to get at any point of the globe a continuous supply of energy, day and night. More than this, reasoning in the abstract, it would seem possible to cause a quick circulation of the medium, and thus draw the energy at a very rapid rate.

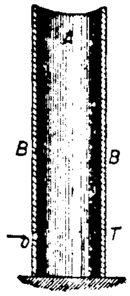


DIAGRAM *b*. OBTAINING ENERGY FROM THE AMBIENT MEDIUM.

A, medium with little energy; *B*, *B*, ambient medium with much energy; *O*, path of the energy.

Here, then, was an idea which, if realizable, afforded a happy solution of the problem of getting energy from the medium. But was it realizable? I convinced myself that it was so in a number of ways, of which one is the following. As regards heat, we are at a high level, which may be represented by the surface of a mountain lake considerably above the sea, the level of which may mark the absolute zero of temperature existing in the interstellar space. Heat, like water, flows from high to low level, and, consequently, just as we can let the water of the lake run down to the sea, so we are able to let heat from the earth's surface travel up into the cold region above. Heat, like water, can perform work in flowing down, and if we had any doubt as to whether we could derive energy from the medium by means of a thermopile, as before described, it would be dispelled by this analogue. But can we produce cold in a given portion of the space and cause the heat to flow in continually? To create such a "sink," or "cold hole," as we might say, in the medium, would be equivalent to producing in the lake a space either empty or filled with something much lighter than water. This we could do by placing in the lake a tank, and pumping all the water out of the latter. We know, then, that the water, if allowed to flow back into the tank, would, theoretically, be able to perform exactly the same amount of work which was used in pumping it out, but not a bit more. Consequently nothing could be gained in this double operation of first raising the water and then letting it fall down. This would mean that it is impossible to create such a sink in the medium. But let us reflect a moment. Heat, though following certain general laws of mechanics, like a fluid, is not such; it is energy which may be converted into other forms of energy as it passes from a high to a low level. To make our mechanical analogy complete and true, we must, therefore, assume that the water, in its passage into the tank, is converted into something else, which may be taken out of it without using any, or by using very little, power. For example, if heat be represented in this analogue by the water of the lake, the oxygen and hydrogen composing the water may illustrate other forms of energy into which the heat is transformed in passing from hot to cold. If the process of heat-transformation were absolutely perfect, no heat at all would arrive at the low level, since all of it would be converted into other forms of energy. Corresponding to this ideal case, all the water flowing into the tank would be decomposed into oxygen and hydrogen before reaching the bottom, and the result would be that water would continually flow in, and yet the tank would remain entirely empty, the gases formed escaping. We would thus produce, by expending initially a certain amount of work to create a sink for the heat or, respectively, the water to flow in, a condition enabling us to get any amount of energy without further effort. This would be an ideal way of obtaining motive power. We do not know of any such absolutely perfect process of heat-conversion, and consequently some heat will generally reach the low level, which means to say, in our mechanical analogue, that some water will arrive at the bottom of the tank, and a gradual and slow filling of the latter will take place, necessitating continuous pumping out. But evidently there will be less to pump out than flows in, or, in other words, less energy will be needed to maintain the initial condition than is developed by the fall, and this is to say that some energy will be gained from the medium. What is not converted in flowing down can just be raised up with its own energy, and what is converted is clear gain. Thus the virtue of the principle I have discovered resides wholly in the conversion of the energy on the downward flow.

FIRST EFFORTS TO PRODUCE THE SELF-ACTING ENGINE—THE MECHANICAL OSCILLATOR—WORK OF DEWAR AND LINDE—LIQUID AIR.

Having recognized this truth, I began to devise means for carrying out my idea, and, after long thought, I finally conceived a combination of apparatus which should make possible the obtaining of power from the medium by a process of continuous cooling of atmospheric air. This apparatus, by continually transforming heat into mechanical work, tended to become colder and colder, and if it only were practicable to reach a very low temperature in this manner, then a sink for the heat could be produced, and energy could be derived from the medium. This seemed to be contrary to the statements of Carnot and Lord Kelvin before referred to, but I concluded from the theory of the process that such a result could be attained. This conclusion I reached, I think, in the latter part of 1883, when I was in Paris, and it was at a time when my mind was being more and more dominated by an invention which I had evolved during the preceding year, and which has since become known under the name of the "rotating magnetic field." During the few years which followed I elaborated further the plan I had imagined, and studied the working conditions, but made little headway. The commercial introduction in this country of the invention before referred to required most of my energies until 1889, when I again took up the idea of the self-acting machine. A closer investigation of the principles involved, and calculation, now showed that the result I aimed at could not be reached in a practical manner by ordinary machinery, as I had in the beginning expected. This led me, as a next step, to the study of a type of engine generally designated as "turbine," which at first seemed to offer better chances for a realization of the idea. Soon I found, however, that the turbine, too, was unsuitable. But my conclusions showed that if an engine of a peculiar kind could be brought to a high degree of perfection, the plan I had conceived was realizable, and I resolved to proceed with the development of such an engine, the primary object of which was to secure the greatest economy of transformation of heat into mechanical energy. A characteristic feature of the engine was that the work-performing piston was not connected with anything else, but was perfectly free to vibrate at an enormous rate. The mechanical difficulties encountered in the construction of this engine were greater than I had anticipated, and I made slow progress. This work was continued until early in 1892, when I went to London, where I saw Professor Dewar's admirable experiments with liquefied gases. Others had liquefied gases before, and notably Ozlewski and Pictet had performed creditable early experiments in this line, but there was such a vigor about the work of Dewar that even the old appeared new. His experiments showed, though in a way different from that I had imagined, that it was possible to reach a very low temperature by transforming heat into mechanical work, and I returned, deeply impressed with what I had seen, and more than ever convinced that my plan was practicable. The work temporarily interrupted was taken up anew, and soon I had in a fair state of perfection the engine which I have named "the mechanical oscillator." In this machine I succeeded in doing away with all packings, valves, and lubrication, and in producing so rapid a vibration of the piston that shafts of tough steel, fastened to the same and vibrated longitudinally, were torn asunder. By combining this engine with a dynamo of special design I produced a highly efficient electrical generator, invaluable in measurements and determinations of physical quantities on account of the unvarying rate of oscillation obtainable by its means. I exhibited several types of this machine, named "mechanical and electrical oscillator," before the Electrical Congress at the World's Fair in Chicago during the summer of 1893, in a lecture which, on account of other pressing work, I was unable to prepare for publication. On that occasion I exposed the principles of the mechanical oscillator, but the original purpose of this machine is explained here for the first time.

In the process, as I had primarily conceived it, for the utilization of the energy of the ambient medium, there were five essential elements in combination, and each of these had to be newly designed and perfected, as no such machines existed. The mechanical oscillator was the first element of this combination, and having perfected this, I turned to the next, which was an air-compressor of a design in certain respects resembling that of the mechanical oscillator. Similar difficulties in the construction were again encountered, but the work was pushed vigorously, and at the close of 1894 I had completed these two elements of the combination, and thus produced an apparatus for compressing air, virtually to any desired pressure, incomparably simpler, smaller, and more efficient than the ordinary. I was just beginning work on the third element, which together with the first two would give a refrigerating machine of exceptional efficiency and simplicity, when a misfortune befell me in the burning of my laboratory, which crippled my labors and delayed me. Shortly afterward Dr. Carl Linde announced the liquefaction of air by a self-cooling process, demonstrating that it was practicable to proceed with the cooling until liquefaction of the air took place. This was the only experimental proof which I was still wanting that energy was obtainable from the medium in the manner contemplated by me.

The liquefaction of air by a self-cooling process was not, as popularly believed, an accidental discovery, but a scientific result which could not have been delayed much longer, and which, in all probability, could not have escaped Dewar. This fascinating advance, I believe, is largely due to the powerful work of this great Scotchman. Nevertheless, Linde's is an immortal achievement. The manufacture of liquid air has been carried on for four years in Germany, on a scale much larger than in any other country, and this strange product has been applied for a variety of purposes. Much was expected of it in the beginning, but so far it has been an industrial ignis fatuus. By the use of such machinery as I am perfecting, its cost will probably be greatly lessened, but even then its commercial success will be questionable. When used as a refrigerant it is uneconomical, as its temperature is unnecessarily low. It is as expensive to maintain a body at a very low temperature as it is to keep it very hot; it takes coal to keep air cold. In oxygen manufacture it cannot yet compete with the electrolytic method. For use as an explosive it is unsuitable, because its low temperature again condemns it to a small efficiency, and for motive-power purposes its cost is still by far too high. It is of interest to note, however, that in driving an engine by liquid air a certain amount of energy may be gained from the engine, or, stated otherwise, from the ambient medium which keeps the engine warm, each two hundred pounds of iron-casting of the latter contributing energy at the rate of about one effective horse-power during one hour. But this gain of the consumer is offset by an equal loss of the producer.

Much of this task on which I have labored so long remains to be done. A number of mechanical details are still to be perfected and some difficulties of a different nature to be mastered, and I cannot hope to produce a self-acting machine deriving energy from the ambient medium for a long time yet, even if all my expectations should materialize. Many circumstances have occurred which have retarded my work of late, but for several reasons the delay was beneficial.

One of these reasons was that I had ample time to consider what the ultimate possibilities of this development might be. I worked for a long time fully convinced that the practical realization of this method of obtaining energy from the sun would be of incalculable industrial value, but the continued study of the subject revealed the fact that while it will be commercially profitable if my expectations are well founded, it will not be so to an extraordinary degree.

It is probable that we shall soon have a self-acting heat-engine capable of deriving moderate amounts of energy from the ambient medium. There is also a possibility—though a small one—that we may obtain electrical energy direct from the sun. This might be the case if the Maxwellian theory is true, according to which electrical vibrations of all rates should emanate from the sun. I am still investigating this subject. Sir William Crookes has shown in his beautiful invention known as the "radiometer" that rays may produce by impact a mechanical effect, and this may lead to some important revelation as to the utilization of the sun's rays in novel ways.

Tesla
Man
Out of Time

Margaret Cheney

1981
Prentice-Hall

In the second year he became obsessed with the idea of producing continuous motion through steady air pressure, and with the possibilities of a vacuum. He grew frantic with his desire to harness these forces but for a long time groped in the dark. Finally, he recalled, "my endeavors crystallized in an invention which was to enable me to achieve what no other mortal ever attempted." It was all part of his consuming dream of being able to fly.

THE NEW YORK TIMES SUNDAY, SEPTEMBER 30, 1894

20

NIKOLA TESLA AND HIS WORK

JOHN FOORD.

ADVANCING WITH CERTAINTY TO GREATEST TRIUMPHS.

Amazing Force Wasted in Making Electric Light—Economical Conversion of Available Energy—The Oscillator, Which Will Give to Most Machines the Value of Old Metal Only—Power of the Medium in Motion Around Us.

"Of the energy that goes to the making of electric light over 90 per cent. is wasted."

The statement is made on the authority of Nikola Tesla, and will be disputed by but few competent electricians. To explain the grounds on which it is made would be to elucidate some of the most elusive problems in physics, and to mark out the path of success for some of the most daring achievements of applied science. For, be it noted, it is electrical energy only of which Mr. Tesla speaks. No account is taken of the waste incurred in the steps of the process preceding the transformation of caloric into mechanical and mechanical into electrical energy.

Accepting Mr. Tesla's startling assertion in all its breadth, what a preposterous dissipation there must be of the energy stored in a lump of coal between its first liberation by combustion and its final emergence in the form of electric light! The waste of heat energy begins in the furnace, and is continued at every step of the process of generation, transmission, and conversion of the steam, so that it is one of the oldest and most stubborn commonplaces of mechanical engineering that a practical engine does not utilize more than 16 per cent., and sometimes not even as much as 5 per cent. of the heat energy employed to operate it. Besides, there is the loss by mechanical friction, in most cases equal to 25 per cent. on an average load of the engine, and the loss by belt friction often equals 15 per cent. more—or 40 per cent. in all used up in the working of the engine itself, and in the transfer of the energy which it communicates to a piece of shafting. Even should that shaft be directly connected with an electric dynamo of good construction for adjustment, there will be a further waste of certainly 10 per cent. in the dynamo itself. If the dynamo be worked in connection with an arc-lighting system, the loss will be as high as 30 per cent., because of the unsteadiness of the regulating mechanism. And, between the dynamo and the carbon filament, or pencil, which is made the centre of an electric light, there ensues, as has been said, a loss of the potential energy conveyed to it of at least 90 per cent. To speak of the finality of scientific achievement in presence of waste on a scale like this is more than absurd.

Science and Invention to Save Energy.

In point of fact, science and her handmaid invention are advancing by deliberate but perfectly confident strides toward a much more economical conversion of available energy. In the case of electric light, one may accept the correctness of the statement that it is not probable that the incandescent lamp can be much improved, and yet be forced to acknowledge that by a single stroke of purely mechanical adaptation, the cost of producing the light may be reduced by one-half or even more. Suppose the steam engine and the electric generator or dynamo, instead of being separate, should be combined in one. Suppose that the average 25 per cent. of loss by mechanical friction in the working of the engine should be saved, likewise the 15 per cent. of loss by belt friction and the 10 per cent. wasted in the dynamo, there would clearly be an addition of 50 per cent. to the available energy obtained from the steam for the purpose of producing electricity. Suppose, further, that the consolidated machine is much simpler, smaller, and lighter than the mechanism which it is to replace; suppose it to be absolutely constant in its action, automatically regulated, and therefore subject to the least possible amount of wear and tear, its advent would certainly mark a revolution, not only in the equipment of electric-light stations, but in many

Nikola Tesla.

other fields of applied energy. These requirements Mr. Tesla seems to have met in the invention of the "oscillator." The essential characteristics of this very remarkable appliance may be briefly described to be the application of the pressure of steam to produce an extremely rapid vibration of a bar of steel or piston, which, in turn, is so adapted to a set of magnets that the mechanical energy of the vibration is converted into electricity. Moreover, under certain conditions, the electrical vibration entirely governs the motion of the bar or piston, and, finally, by means of this appliance, the extraordinary result is reached, that to all intents and purposes an absolutely constant vibration is established.

For reasons difficult to make plain without recourse to technical language, the great rapidity of this piston action admits of the use of steam at very high pressure, indeed, and lends itself to the development in this simply and economically constructed machine of power much beyond that obtainable in the most costly expansion engines using a similar amount of steam. The primary purpose of the "oscillator" is to convert by a process as direct as possible the energy of steam into that of electricity. It has no rotary motion, because for its purpose rotary motion is not only unnecessary, but wasteful. If it be a question of generating electricity for the production of light, all rotary motion in the mechanism is merely so much dissipation of energy. For that and other reasons there can be no doubt about the impression which the "oscillator" will make in the lighting business. But if the machine does all that its inventor believes it can and will, it is also destined to have a very profound influence indeed on all the great agencies of production and transportation. The fact is already recognized by all progressive men that the cheapest way of distributing power is by means of electricity. To say nothing about the enormous frictional losses due to the employment of extended systems of shafting and belting, account must be taken of the power wasted in moving long lines of shafting for the purpose of operating the small part which may be actually in use. When the distribution of power is made by electric energy, it is used only when and where it is needed.

Now, since it is recognized that it is most economical to convert the energy of the steam first into electricity, and then reconvert it into any form of motion that may be required, it is clear that the most successful apparatus of power production adapted to modern needs will be the one best fitted for the simple, direct, and economical generation of electricity. Mr. Tesla has taken what may be called the core of a steam engine and the core of an electrical dynamo, given them a harmonious mechanical adjustment, and produced a machine which has in it the potentiality of reducing to the rank of old metal half the machinery at present moving on the face of the globe. It may come to do the work of the engines of an ocean steamship within a small part of the space they occupy and at a fraction of their cost, both of construction and operation. It will do the work, if at all, without jar or pounding, and will reduce to a minimum the risk of derangement or breakage. There is nothing in the whole range of mechanical construction, from railway locomotives to stamp mills, which such an invention may not revolutionize.

Paradoxes Tesla's Machine Involves.

It will be perceived that what has been outlined in regard to the construction of the "oscillator" involves some paradoxes in mechanics. If it is not to wear out, it must be destitute of friction, and must, therefore, present the anomaly of a steam cylinder and piston without packing, and yet admitting of no escape of steam. Still further, to bear out the claim of practical imperishability, the motion of the piston must be such as to preclude molecular change in the metal calculated to weaken it, and the whole machine must be extremely simple in its adjustments and mode of operation in comparison with the highly-complicated engines of to-day. There are engineers who will pronounce the attainment of these conditions to be impossible. But scientific men are becoming very cautious about the use of the word "impossible." It is less than twenty-five years since an electrical engineer of some reputation, then engaged in the construction of the present fire-alarm system of New-York, said to the writer that it would pay to use electricity as a motive power when we could afford to feed steam boiler furnaces with piano frames. A steel rod vibrating without mechanical friction, and without loss directly transforming the energy of its vibration into electrical energy, may appear to be as much of a dream to the humdrum machinist of to-day, even on the eve of its realization. But when the genius of a scientific investigator of the first rank is combined with the genius of the inventor, humdrum people must prepare to be startled.

They doubtless will be when Mr. Tesla's machine is sufficiently perfected to be introduced to the public, and it may surprise people who are not humdrum to learn that this very beautiful piece of mechanical adaptation derives its chief value in the eyes of its inventor from the fact that it will enable him to pursue with new confidence some very far-reaching scientific investigations. It has given him a new tool, which possesses certain indispensable qualities of certainty and uniformity of action hitherto lacking. This is by no means the only case in Tesla's scientific career in which he has demonstrated that practical achievement comes directly in the line of speculative advance. At the very outset of the path of investigation which has already led him to a position of distinguished eminence, he showed how the principles of the rotating magnetic field could be so applied as to reduce to a far simpler expression the cumbrous and costly form of armature employed in the construction of motors. Scores of patents have been taken out by other men on inventions based on suggestions of his, which he has freely made for the guidance of his fellow-workers. But, brilliant as have been the practical achievements which directly or indirectly stand to Tesla's credit, he is only at the beginning of these, because he aims so extremely high. Electricians have an enormous respect for the man who applied the alternating current to motors, dispensed with brushes and commutators, and made an efficient armature, formerly about as big as a cart wheel, not much larger than its hub. But these seem relatively small things for the man whose goal of effort can be thus outlined: "We are whirling through space at an inconceivable speed; all around us everything is spinning, everything is moving, everything is energy. There must be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort from the store forever inexhaustible, humanity will advance with giant strides." This was said before the American Institute of Electrical Engineers at Columbia College in 1891. It was only the other day that Tesla repeated the same idea to the writer in a more confident form. "I expect to live to be able to set a machine in the middle of this room and move it by no other agency than the energy of the medium in motion around us." The three years which have elapsed since the delivery of the lecture have served only to deepen his conviction that the consummation which he outlined then is neither impracticable nor visionary.

Oscillator a Tool of Larger Problems.

When the key is found to the elimination of the 90 per cent. of waste incidental to the production of electric light, then that consummation will not be far from our grasp. But, let it be noted that, however efficient the machine already referred to may prove to be in reducing the cost of generating the electricity that goes to the production of light, it marks only the first step toward the solution of the larger problems in the working out of which it is to serve as a tool. The scientific as distinguished from the commercial value of the new machine, consists, as its inventor has pointed out, in its capacity to produce very rapidly alternating currents of electricity whose frequency, i. e., rate of oscillation, whether high or low, is absolutely constant. Further progress in the direction whither Mr. Tesla's experiments are leading was all but impossible while the latter requirement was lacking. Some of the factors of the problem which Tesla has set out to solve elude popular definition, and some, indeed, almost transcend comprehension. But when it is stated that light is the result of etheric vibration of a very high pitch and of a definite kind, much higher than the heat-producing vibration, we get some grasp of the idea that light production must be wasteful while it continues to be impossible to obtain the higher light vibrations without passing through the lower heat vibrations. No apparatus yet designed for the production of light by conversion from any source of energy, whether the process be electrical, chemical [illegible] to avoid that nec[illegible] escape from it seems to be as impossible as from that of imparting to a body a certain velocity without passing through all lower velocities.

But we shall not be able to follow very far in the path which the advanced guard of modern science is treading if the laws of what we have been accustomed to call matter are regarded as the measure of the universe. Matter is a term whose significance science has greatly enlarged. It has become a scientific postulate that what is commonly called the void of space is filled with a medium which, though imperceptible to any human sense, has yet material properties. That is to say, the all-enveloping, all-pervading ether—the eternal ocean without a shore, in whose immensity suns and planets are but bubbles of varying size and hue—is the carrier and transmitter of all primary forms of energy, and perhaps is the material from which the tangible and visible universe has come. The question of the schoolbooks is relevant here: "If light is motion, what moves?" Beyond that thin envelope that we call the earth's atmosphere, there are the depths of interplanetary space, through which must be communicated to us the form of energy known as light. But as the science primers again remark, "empty space can neither receive nor communicate motion." And so we come to the only hypothesis that accords with the facts, that of the etheric atoms, namely, and the sublime expectations to which that theory has given birth. The inconceivably minute atom, "the ulterior element of the universe's structure, is tossed about," as Tesla puts it, "in space eternally, a play to external influences, like a boat in a troubled sea." It moves, it vibrates, and that with the most marvelous rapidity, and by the very necessity of its existence, for matter at rest would be dead matter—quite an inconceivable thing, in spite of the popular impression to the contrary.

Possibilities in Appalling Figures.

Science says that light must travel at the rate of 186,000 miles a second; and that light is the product of an etheric vibration whose rate is about 500,000,000,000,000 a second, but science has hardly stopped to consider what profound possibilities there are in the forces which such appalling figures convey. Even now we know very little of what electricity is, but it has been one of the triumphs of modern investigation to identify electro-magnetic manifestations of energy with those of light and heat. Out of this identification has been born the desire to reach to the very source of all the transformed, accumulated, and stored-up supplies of this energy—such as coal, gas, and oil—which there is so much waste in liberating from their mundane environment, and to take a lead directly from the inexhaustible fountain of it all. It is toward such an ideal that Tesla is constantly striving. There can be nothing more exact, more severely scientific, than his methods of investigation; his experiments lead him from point to point along a solid path of ascertained fact. But he never fails to remember that speculation is the basis of investigation, and thus it is that, in following his experiments, the impression of wonder and admiration received from the immediate achievement quickly gives place to a feeling akin to awe at the grandeur of the conception, which is the end of ultimate attainment.

For example, in his London lecture of two years ago, Tesla demonstrated not only the fallacy of the idea that an electric motor could be operated only with a double connection between it and the generator—that is, with a wire for the return, as well as the transmission of the current—but he showed that the motor could be operated with one wire only, or without any connecting wire at all. In his own words: "It is not necessary to have even a single connection between the motor and the generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller." Now, from this demonstration of the possibility of working a motor without connecting wires by currents passed through the earth or air, a far-reaching possibility is revealed. For, "alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. To reach a number of miles into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation, luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds of thousands of horse power, motors or lamps might be operated at considerable distances from the stationary sources."

No Need of Transmitting Power at All.

This is a sufficiently impressive perspective, but it is referred to by Tesla only as a possibility, for, dipping into the future further than most human eyes can see, he asserts that we shall have no need to transmit power in this or any other way. "We shall have no need to transmit power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. * * * Throughout space there is energy. Is this energy static or kinetic? If static, our hopes are in vain; if kinetic—and this we know it is for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature." To state this in ordinary language, if we live amid a medium through which there is no continuous flow of energy, this realization would appear to be impossible, but if everything around us is in constant motion, then human ingenuity must find a means of converting that energy to productive uses.

Here we have indeed the fairy tales of science, but, rightly considered, no more marvelous than many things we have long ceased to wonder at, because they are so familiar. It is, after all, in the interpretation of the familiar phenomena that science reaches a higher range of achievement, and it is only when science accepts the familiar phenomena without interrogating them that it fails to advance. "Lighting the gas" is a common everyday operation which nobody stops to wonder at, and so too, has become the act of touching a button and seeing a carbon filament become luminous inside of an air-tight glass bulb. But if science had the power to discern more clearly the hidden processes of nature and reveal to us the secret of the forces which are brought into action by either of these two simple proceedings, it would be able to resolve a great many of the riddles of the universe which remain unread. One does not advance very far toward the comprehension of what takes place during the incandescence of a gas at the ordinary pressure of the atmosphere by calling it a form of radiant energy. But we do come a step nearer to an intelligent grasp of the facts when we find that the luminosity is due to the shocks of impacts of the gaseous molecules. To quote from Tesla again: "Just as molecules or atoms beating upon a solid body excite phosphorescence in it or render it incandescent, so when colliding among themselves they produce similar phenomena." But, as our authority adds, "this is a very insufficient explanation and concerns only the crude mechanism."

Take the problem of the incandescence of the filament in the bulb, which, if not more complicated, is at least more elusive, than that of the incandescence of the gas in an ordinary burner. Here atmospheric air has been exhausted, not by any means perfectly, it is true, but as near an approach to what is called a vacuum has been made as is usual in commercial appliances. A "vacuum" is, however, merely a relative term. In addition to a certain residue of atmospheric air, the etheric medium remains, for, as the text-books put the case, "an attempt to pump it out of space would be like trying to pump water with a sieve for a piston," and a sieve, it may be added, with very wide meshes indeed. When the electric vibrations passed along the wire are communicated to the filament within the bulb, they cause a disturbance of its molecules so violent as to produce both heat and light, but, to the despair of the man of science, unfortunately, very little of the latter. Light comes as the filament gives out an incandescent glow, but the light would be a much more economical one if the molecules or atoms of the surrounding gas or ether could be made to glow, too. And here we encounter one of the most instructive of the Tesla paradoxes, which can be best expressed in his own words: "Any one who begins a study of the problem will be apt to think that what is wanted in a lamp with an electrode is a very high degree of incandescence of the electrode. There he will be mistaken." The high incandescence of the button is a necessary evil, but what is really wanted is the high incandescence of the gas surrounding the button. In other words, the problem in such a lamp is to bring a mass of gas to the highest possible incandescence."

What is to be the Light of the Future?

To follow this idea further, it is necessary to distinguish between the origin of the incandescence of the filament and that of a mere button at the end of the conducting wire of the lamp. In the case of the filament, the luminosity is due partly to the action of its component molecules on each other when excited by the electric current, and partly to the bombardment or impact of the etheric particles, which have also received their electric charge and are being attracted, repelled, and agitated with tremendous velocity. The incandescence of the button, on the other hand, is caused almost solely by its very active bombardment by these inconceivably minute electrified atoms of the gas or ether. And here we begin to see why Mr. Tesla believes that the production of a small electrode (or terminal button) capable of withstanding enormous temperatures is of the greatest importance in the manufacture of light. For, as he explains it, "the intensity of the light emitted depends principally on the frequency and potential of the impulses and on the electric density on the surface of the electrode. It is of the greatest importance to employ the smallest possible button, in order to push the density very far. Under the violent impact of the molecules of the gas surrounding it, the small electrode is, of course, brought to an extremely high temperature, but around it is a mass of highly-incandescent gas, a flame photosphere many hundred times the volume of the electrode."

So far, the problems of practical adaptation, which, however important and interesting, appeal less powerfully to the imagination than the higher lights of the Tesla experiments. But Tesla never flies so high as to forget the "one and only desire" which he shares with all lovers of science and of progress, "to reach a result of utility to men in any direction to which thought or experiment may lead." So, when he shows how a hollow glass tube, from which the air has been exhausted before being sealed at each end, can be made to glow with light throughout its entire length by the mere act of holding it in the hand in a room in which electrostatic forces of sufficient strength have been made to act, he is thinking how such experiments may lead to the production of an efficient illuminating device. For, as he puts it, "every thinker, when considering the barbarous methods employed, the deplorable losses incurred in our best system of light production, must have asked himself, What is likely to be the light of the future? Is it to be an incandescent solid, as in the present lamp, or an incandescent gas, or a phosphorescent body, or something like a burner, but incomparably more efficient?"

Explanation of Electrostatic Force.

In such a quest one may, however, soar very high. Take the very striking and beautiful vacuum-tube experiment to participate in which makes one feel as if the veritable sceptre of the world of light were put in one's hand, what does the experimenter mean when he says that his conviction has grown strong that "to whatever kind of motion light may be due, it is produced by tremendous electrostatic stresses vibrating with extreme rapidity"? That raises the further question of what is electrostatic force, and here let Tesla speak for himself: "It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an indefinite variety of ways, according to Nature's fanciful designs, and form all these wondrous structures we see around us; it is, in fact, if our present views be true, the most important force for us to consider in nature." To establish what is called an electrostatic alternating field, acting through the whole extent of a room, requires an adjustment of electrical apparatus whose description belongs to technical, not to popular, study. Let it suffice to say that when two conducting bodies are insulated and electrified an electrostatic force is said to be acting between them. "This force manifests itself in attractions, repulsions, and stresses in the bodies and space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light or streamers, as they are called." To demonstrate the potency of such a force, the experimenter, standing within an electrostatic field in whose creation a peculiar induction coil plays an important part, brings a piece of metal which he holds in his hand in touch with the end of the secondary wire of the coil. His arm is then traversed by a powerful electric current, vibrating at about the rate of 1,000,000 times a second.

All around the electrostatic force makes itself felt and the air molecules and particles of dust flying about are acted upon and are hammering violently against his body. So great is this agitation of the particles that when the lights are turned out streams of feeble light are seen to appear on some parts of the body. When such a "streamer" breaks out it produces a sensation like the pricking of a needle. Were the potentials, or pressures, sufficiently high, and the frequency of the vibration, or rapidity, rather low, the skin would probably be ruptured under the tremendous strain and the blood would rush out with great force in the form of fine spray or jets so thin as to be invisible. The streams of light which are the most frequently cited, and overstated, of the Tesla marvels, are due to a potential of about 200,000 volts, alternating in rather irregular intervals, but, as already stated, at something like 1,000,000 times a second. According to his own statement: "A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least." For the benefit of the adventurous amateurs of either sex desirous of experiencing, and for the information of artists desirous of illustrating, this novel effect, it should be stated that the body cannot very well be enveloped in a complete sheet of electro-magnetic flame with the clothes on.

Tesla, Scientist, Inventor, and Seer.

But such an experiment, however well calculated to dazzle and amaze, has a significance much less profound than the production inside of an exhausted glass tube of a luminous thread possessing rigidity. This is one of Tesla's most beautiful and most significant demonstrations, and it appeals very powerfully to the scientific imagination, because it touches some of the most occult processes of the arcanum of nature. As Mr. Tesla puts it, "the demonstration of the fact that a vibrating gaseous column possesses rigidity, must greatly modify the views of thinkers. When with low frequencies and insignificant potentials indications of that property may be noted, how must a gaseous medium behave under the influence of enormous electrostatic stresses, which may be active in the interstellar space, and which may alternate with inconceivable rapidity? The existence of such an electrostatic, rhythmically-throbbing force—of a vibrating electrostatic field—would show a possible way how solids might have formed from the ultra-gaseous uterus, and how transverse and all kinds of vibrations may be transmitted through a gaseous medium filling all space."

Sic itur ad astra! And thus we reach celestial heights of contemplation, even as we search for higher forms of incandescence, to light the murky nights of this little planet withal. This it is to have the insight of the poet joined to the tireless patience of the seeker after exact truth; to have a philosophic mind quickened by imagination, and a penetrating intelligence directed by the enthusiasm of humanity. This it is to be advancing without haste, but without rest, with a serene and modest certainty, toward the goal of achievements which will give the next century its characteristic distinction, as surely as the triumphs of steam have stamped their influence on the one now drawing to a close. This it is to be a scientist, inventor, and seer in one, to be one of the most remarkable men of this or any other time—to be Nikola Tesla.

/5.626.459/5,107,682/4,663,939/3,826,092/

A "NEW" ENERGY SOURCE?

Can this energy form, using the Maximum Ambient Cycle be a source for energy on our horizon?

by 773-731-6040?

Thomas L. Cosby Chicago IL 60617

The Maximum Ambient Cycle is an internationally patented engine cycle. It has two American, and Australian, Israeli, Mexican patents, and patents pending in ten other countries. It is described as a work producing cycle using the ambient air as primary energy source and creating an internal lower than ambient temperature heat exchanger from a work producing adiabatic process.

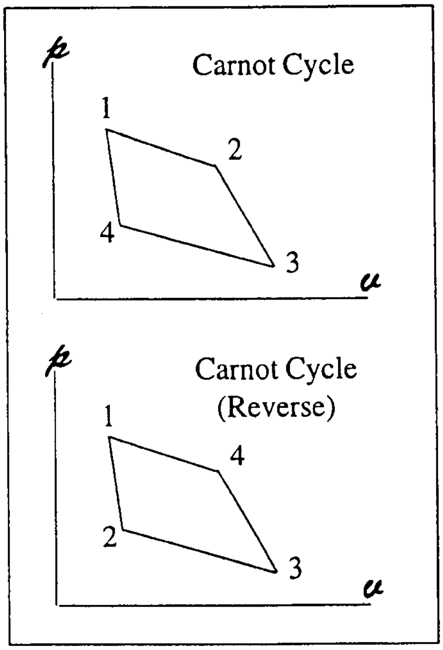
Unknown by most, and unacknowledged by science, is the fact that we live on the bottom of a sea of unlimited energy! If there was no energy in the gas that we call the atmosphere, we could not exist because it would be a solid mass of frozen matter. We are very much like the "Ancient Mariner" when he decried: "Water! Water everywhere and not a drop to drink."

We can't use the energy because we need a temperature differential for work to be created from heat energy, so because this low level energy has no place to go, it can't be used.

Work is generated from the standard heat engine cycle(s) by using fuel to create a high temperature and a differential between the lower temperature atmosphere.

In the air-conditioning cycle, work is applied to compress a gas which raises its temperature. The heat in dissipated to the lower temperature atmosphere. Now a miracle occurs: gas expansion results in a cooler than atmospheric temperature gas. The gas can now absorb heat from something and cool it.

Both of these phenomena are described by the Carnot Cycle.



Several observations and comments must be made about the cycle and the type of engine described. It is now accepted without discussion that there is only one type of engine--the heat engine. It has been accepted for so long that most scientists don't realize this truth that forms the basis of the first and second laws of thermodynamics. Few, if any, know the definition of a heat engine and the limited application and the conditions of the various sloganized statements of the second law of thermodynamics. Because there is only one type of engine it is axiomatic that it applies to all engines!

When Carnot made the analysis, there was one and only one model available - the steam piston engine!

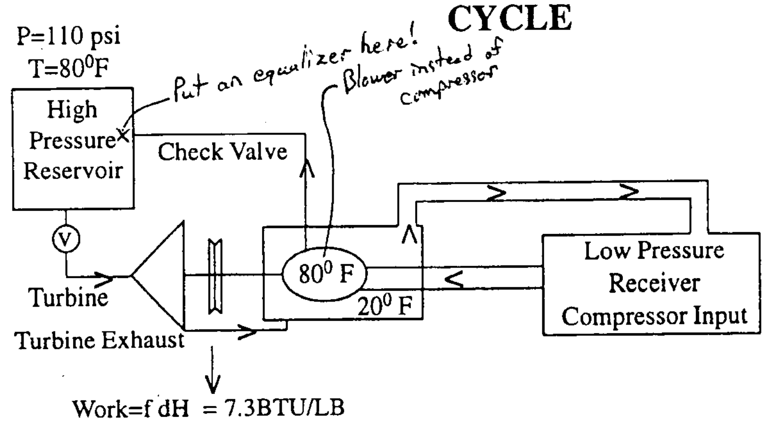
The MAXIMUM AMBIENT CYCLE did not just happen, it evolved. It is the result of one man's persistent search for the truth in energy to work transformation and the way to input the least amount of energy into an engine or cycle by internal energy exchanges, or in popular terms-recycling. It is the result of 40 years effort by a sole inventor.

The MAXIMUM AMBIENT CYCLE is a work producing gas cycle and engine. It has for components high and low pressure receivers, a turbine to produce work by expansion of high pressure gas, a compressor to re-pressurize that gas, a heat exchanger to absorb heat of compression by using low temperature turbine exhaust, thereby reducing compressor work and simultaneously reheating the turbine exhaust. The internal energy exchange makes it possible to obtain a net work output and to reduce input heat requirements.

Any heat input to the low temperature exhaust may be absorbed from the compression process or the atmosphere(see air-conditioning Carnot cycle). The major part of the compression - volume reduction may be accomplished by introducing the gas into a cooler compressor. Final pressurization is done by using a portion of the turbine output. Initially the system is at near vacuum except for the high pressure reservoir. The fluid is R-22.

Objections to the cycle have been universally based upon the Kelvin-Planck (K-P) statement of the 2nd law: "It is impossible to produce work while interacting with only one reservation. What this means, relative to this cycle is that both the high and low pressure reservoirs are at the same atmospheric temperature therefore -only one reservoir (temperature). While it is true that this is the case, the heat exchange mechanism is in the exchanger.

MAXIMUM AMBIENT CYCLE



A WORK PRODUCING CYCLE USING THE AMBIENT AIR AS PRIMARY ENERGY SOURCE AND CREATING AN INTERNAL LOWER THAN AMBIENT TEMPERATURE HEAT EXHANGER FROM THE TURBINE EXHAUST

Implicit in the K-P statement is that there must be a temperature differential for heat to flow, we agree. In the heat exchanger low temperature turbine exhaust is in contact with the higher temperature compressor and fluid from the low pressure reservoir.

In this cycle it is advantageous to raise the temperature of the gas coming into the compressor because of the greater temperature differential this causes. This expedites heat transfer between the compression process and the turbine exhaust.

A more scientific description of the K-P statement was provided in 1913 by Lewis, J.,*American Chemical Society*: " . . .The maximum work that can be obtained from a system on passing reversibly from state 1 to state 2 at the same temperature is of great importance, for it is independent of the particular process employed. If this were not true, then by proceeding from 1 to 2 by one isothermal process and returning from 2 to 1 by another isothermal process requiring less work, a certain amount of net work could be gained. "What is most often overlooked in the Carnot Heat engine cycle is that the work is the difference between the two isothermal processes - at different temperatures.

It is also missed that for isothermal processes, ala the Carnot cycle to occur, a continuous flow of heat is required-- in and out of the system. The other objection resulting from the R-P statement is that there is no rejection of heat to a low temperature sink. HEREIN lies the rub. Sink as commonly understood means an external sink.

Reviewing the Carnot engine which analyses the path of a piston, it can be readily understood that once the piston has reached the end of its stroke, it must be restored to the starting position. This is accomplished first by heat rejection to a sink by a continuous removal of heat. For this to be fully understood it must be remembered that work was accomplished by a continuous supply of heat. That part of the heat that remains after work production, because it cannot all be converted to work, must be discarded.

If, on the other hand we have compressed gas, work can be performed by allowing it to expand adiabatically, that is without any input heat. The result will be work and a low temperature exhaust gas. If the starting point was atmospheric temperature, it is obvious that it will be below this temperature making it possible to absorb heat from the atmosphere or some other higher temperature body. There is no trick in releasing the genie and obtaining work, the trick is to get it back into the bottle without giving the work back.

This is where isothermal compression comes into play. Theoretically, the work of compression is equal to the heat of compression (really!) In the Carnot process, the gas is slightly compressed so that the temperature rises slightly and heat is absorbed by the sink-after work is put into the process. So, work *must* be put into the process to "Squeeze" the heat out.

In this cycle, gas to be compressed is introduced into a colder compressor where it contracts or shrinks spontaneously because it is chilled because of the temperature difference. Compression work is "free," but also the heat for the turbine exhaust reheat. A spontaneous exchange occurs without work input.

Our initial goal was isothermal compression, but serendipity gave us a bonus! By introducing the gas into a cooler environment, application of work is unnecessary! (Well-almost).

Summation. This cycle and resulting engine technology represents a major departure in the way that energy use and conversion is conceived. The first law teaches that energy is neither created nor destroyed, but merely transformed from one form to another. The second teaches that a Heat Engine can only use a fraction of the heat that crosses it boundary. This cycle teaches that no heat need "cross" the boundary of an engine and that work is a function of the energy interactions within the engine.

What does it mean? First, it means that for 150 years we have used a yardstick that has limited use. Second, by reading the text books, analytical thinking has been discouraged. In 1896 an author stated that it was as good as it was ever going to get. Enrico Fermi and Albert Einstein both stated their belief that the second law was inviolate. We agree but not in the same sense. Their belief was final, mine states and demands an alternate mode be sought.

For eons mankind has put a kettle over a fire, for food preparation, for work production, ala the steam engine, for warmth. The Internal Combustion engines are but a modification of the basic pot on the fire. Surely, as mankind reaches for the stars, splits the atom, employs electrons, sound and light waves, surely science can present a better option than the pot over the fire.

Philosophically what? Mankind has also been hampered by his disbelief in something for nothing, this despite the fact that millions, if not billions request favors from a supreme being without giving a second thought. Nature does not care about the economic or selfish desires of mankind and performs whether man believes or accepts her laws or not.

Where to from here? Use of this cycle and the new vistas presented, offers hope that mankind in his search for energy to provide the luxurious life that is Universally desired, will not pollute and poison mother earth. The cavalry has arrived in time!__TC

EXTRAORDINARY SCIENCE

WITH J.W. McGINNIS
President,
International Tesla Society

RADIO HOUR

SHORTWAVE RADIO
Heard Around the World

7.435 MHz - Saturdays
8:00 AM Eastern US

5.070 MHz - Sundays
Midnight Eastern US

AM RADIO
on
Talk Radio Network
(TRN)
1-541-664-8829
CALL FOR TIME &
STATION IN YOUR AREA
(Now over 50 Stations Nationally)

Brought to you by:
The
INTERNATIONAL
TESLA SOCIETY
A 501(C)(3) Not for Profit
Educational and Scientific
Organization

"The Fastest Growing
Organization of its kind
in the World"

WATCH THE WEB

http://www.tesla.org
(Note: Not .com)

— ATMOSPHERIC ENERGY —

HARNESSING THE 'POWERS' OF THE ATMOSPHERE

by Anthony M. Hansen

Since early times mankind has had a constant and reliable source of power in the form of the wind. Man was quick to find ingenious but simple applications for this force of nature. Obvious examples are the sail and the windmill. What is not so obvious are the underlying principles, as defined in physics books; to be more specific, the principles of thermodynamics.

Thermodynamics is connected with heat; that is to say, measurement of heat, and laws relating to the conversion of heat into mechanical work. Nature gives a wonderful example in the movement of the wind. The atmosphere basically moves because over the land, for example, the temperature can be higher than over the ocean, with the result that the hot air rises over the land and the cooler air flows in to take its place.

In thermodynamics, the terms T_1 and T_2 are frequently quoted. T_1 usually refers to a specific temperature and T_2 refers to a temperature which is less than T_1. Otherwise expressed, the bigger the temperature difference, the more energy there is available. Applying this to the movement of the wind, if the atmospheric temperature of the Earth were the same everywhere, presumably there would be no winds.

One of the earliest attempts to harness the power of the atmosphere, apart from using the windmill and the sail, was attempted successfully by Newcomen, a Dartmouth blacksmith, and patented in 1705. The device consisted of a vertical cylinder and a piston which was connected to a horizontal beam. The other end of the beam was connected to the piston of a pump. The weight of this side of the beam was sufficient to draw the piston to the top of the cylinder. Steam was admitted from a boiler through a valve to the cylinder. When the supply of steam was turned off and some water injected into the cylinder, the result was that the steam condensed, forming a partial vacuum inside the cylinder. The pressure of the atmosphere acting on the top half of the piston forced it down. By continually repeating this process, a powerful machine was put to work pumping water.

In 1827, Robert Stirling took out his patent for a hot air engine which used the heat of the air. From the very start, the hot air engine offered an irresistible fascination for the inventor because even the crudest attempts with it always resulted in an efficiency far superior to that of the steam engine. This is readily explained as being due to the far greater temperature range possible working with air than is possible with steam. This is because the efficiency of an engine depends upon the limits of temperature to which the working fluid is subjected. It is practical to use a higher working temperature with air than with steam because there is no fixed relation between the pressure and temperature of air, such as exists in the case of steam.

PUTTING COMPRESSED AIR TO WORK

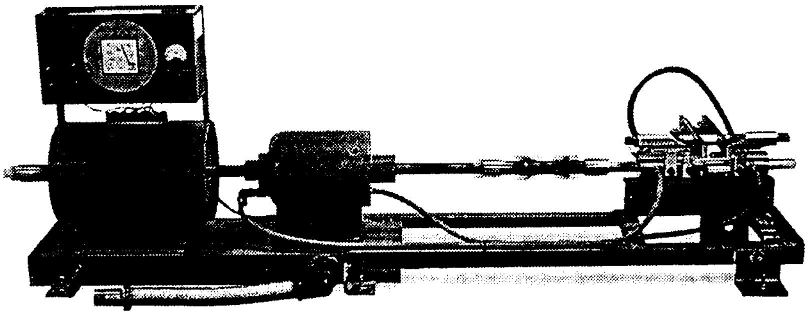
Having reviewed at some length the various forms of machinery available, I decided as a starting point that the windmill took a lot of beating as far as reliability and power were concerned. For example, it is quite easy to obtain six to 10 horsepower from the wind.

It is obvious that power, or the rate at which work is done, has nothing to do with the quantity of work accomplished. A very slow rate may accomplish a great deal of work, if it only keeps at it long enough, while a very high rate may be represented by a very small quantity of work, provided it be expended in a sufficiently short space of time. Thus, a windmill of only a few horsepower, compressing air by working steadily day and night for weeks and months, may compress millions of cubic feet of air and thereby perform a vast amount of work.

The air which is compressed by the windmill is stored in suitably large pressure vessels or compressed air tanks. To give an idea of size, an LP gas tank similar to the ones used in service stations is ideal. These can be pumped up to a pressure of 200 to 300 psi. This represents a considerable amount of energy stored in a pressure vessel in the form of compressed air.

A convenient way to use this compressed air is to use the pressure of the air to move a piston in a cylinder, preferably in alternate directions. This reciprocating force moves a conductor through a magnetic field, thus generating electricity. If, for example, a piston had five square inches of surface area and a pressure of 100 psi were applied to it, we would obviously have a piston in a cylinder with 500 pounds of push. In such a case, the load from the conductor going through the magnetic field ideally should be about 400 pounds resistance.

When the conditions are similar to this, the air has no choice but to give up the heat



A Dynamic Linear Mass Accelerator (DLMA Linear Engine) working prototype, producing 250 volts at 50 hertz.

it contains and thus turn heat into mechanical work. This results in the air becoming very cold. The degree of coldness is directly proportional to the applied force and the resistance it encounters. In other words, the heavier the load, the colder the temperature.

THIRD LAW OF THERMODYNAMICS

The third law of thermodynamics states that there are four essential conditions necessary for a heat engine to work. This applies to internal combustion engines such as LP gas, petrol, diesel, steam or compressed air. These conditions are:

1) **There must be a source of heat.** As an example, with internal combustion engines the source of heat is the burning of fuels such as LP gas or petrol. This heat is applied to the compressed air in the cylinder at the moment of ignition. The heat of combustion causes the compressed air molecules—already at a pressure, which may be from 150 to 300 psi—to vibrate more intensely, thus increasing the pressure which is applied to the piston face. The heat energy can now be turned into mechanical work.

2) **There must be a temperature difference in the process.** As an example, the temperature of combustion may be 700° to 900° Fahrenheit (371° to 482° Celsius) while the temperature of the atmosphere may be 70°F (21°C). This is represented in thermodynamic terms as T_1 and T_2—here, T_1 being 700° to 900°F and T_2 being 70°F. It can thus be seen that, with such a large temperature difference, a considerable amount of power can be developed.

3) **There must be a carrier of the heat energy.** This basically means that the air is a medium which carries the heat, just like a bucket can carry water.

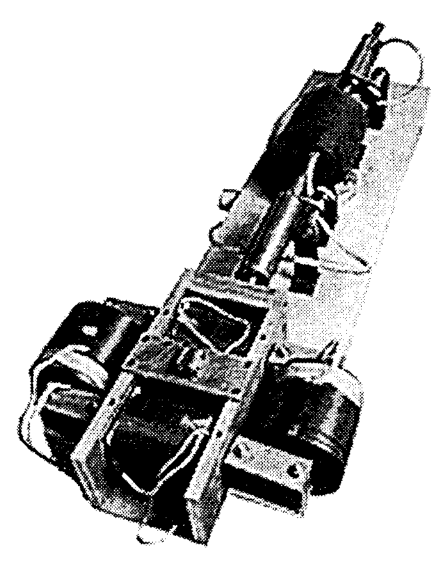
4) **There must be a method or means of turning heat into mechanical work.** In this case it is the familiar piston in the cylinder, examples of which have been given in the previous essential conditions.

THE THIRD LAW APPLIED TO COMPRESSED AIR ENGINES

Applying the above conditions of the third law to compressed air engines, if a piston is driven by compressed air at 200 psi through a quarter of its stroke and then the air supply is cut off, and if the piston has to do work, it is quite easy to attain temperatures in the exhaust of minus 50°F.

This relates to T_2 in the temperature difference scale, T_1 being the temperature of the atmosphere—let's say, 70°F. It can now be seen that a considerable temperature difference exists—120°F in this case. This conforms with the second essential condition of the third law.

Having established the temperature difference, it is now necessary to feed in the heat from the atmosphere. As the atmospheric air contains the heat (condition 3), if the engine has heat exchanger fins, and if they be of suitable size, heat from the atmosphere will flow into the engine and, by doing so, should be turned into mechanical work, thus adding to the efficiency of the machine.



The MKII working prototype of the DLMA Linear Engine.

IMPROVING ENGINE EFFICIENCY

Otto was the first to develop the four-stroke cycle and was also one of the first to propose using a so-called free piston engine running on fuel.

Some years later, in 1869, George Westinghouse patented a steam-driven free piston compressor.

This principle was improved upon by Nikola Tesla in 1894. His design used machined grooves in the piston to let in the steam or air to drive the piston. The main problem with this design is that under a heavy load the stroke will shorten, with the result that the air supply is cut off.

Having studied the various types of reciprocating engines, I decided that apart from trying to follow the third law, certain other essential features were necessary:

1) **Floating valves** that can slide on the reciprocating shaft, towards and away from each other. This makes it possible to vary the length of the stroke, thereby compensating for heavy loads.

2) **A variable inertia system**, enabling mass to be added or removed from a moving system. This is used to change the period of the reciprocating engine.

3) **Heat exchanger fins**. By adding fins to this type of engine, heat can be caused to flow into the engine, thus adding to its efficiency.

By applying the above-mentioned features, a simple and efficient power conversion system is possible.

CONCLUDING REMARKS

Much has been written on the subject of heat engines and their operating principles—so much, in fact, that to the casual reader it would appear that there is little, if any, part of the subject left untouched.

Yet the present-day literature may generally be divided into two classes: the non-technical and the technical. The technical literature is often so severely technical and theoretical as to obscure the underlying practical aspects. The student who is not at home with mathematical gymnastics may well be excused for being worried at an imposing array of formulae which, however beautiful and concise in themselves, possess no interest and serve no useful purpose when they fail to convey their significance.

It is my hope that the given explanations make the underlying concepts of thermodynamics—on which all heat engines work—more understandable and interesting.

For further information, contact:
Anthony M. Hansen
Linear Energy Corporation Ltd
PO Box 7217 Gold Coast Mail Centre
Bundall, Qld 4217, Australia
Phone: +61 (0)7 5574 1810
Fax: +61 (0)7 5574 1820
E-mail: linearen@OntheNet.com.au
Web: http://www.linearenergy.com.au
(See advert on the Inside Cover)

INVEST NOW

in R&D to commercialise the

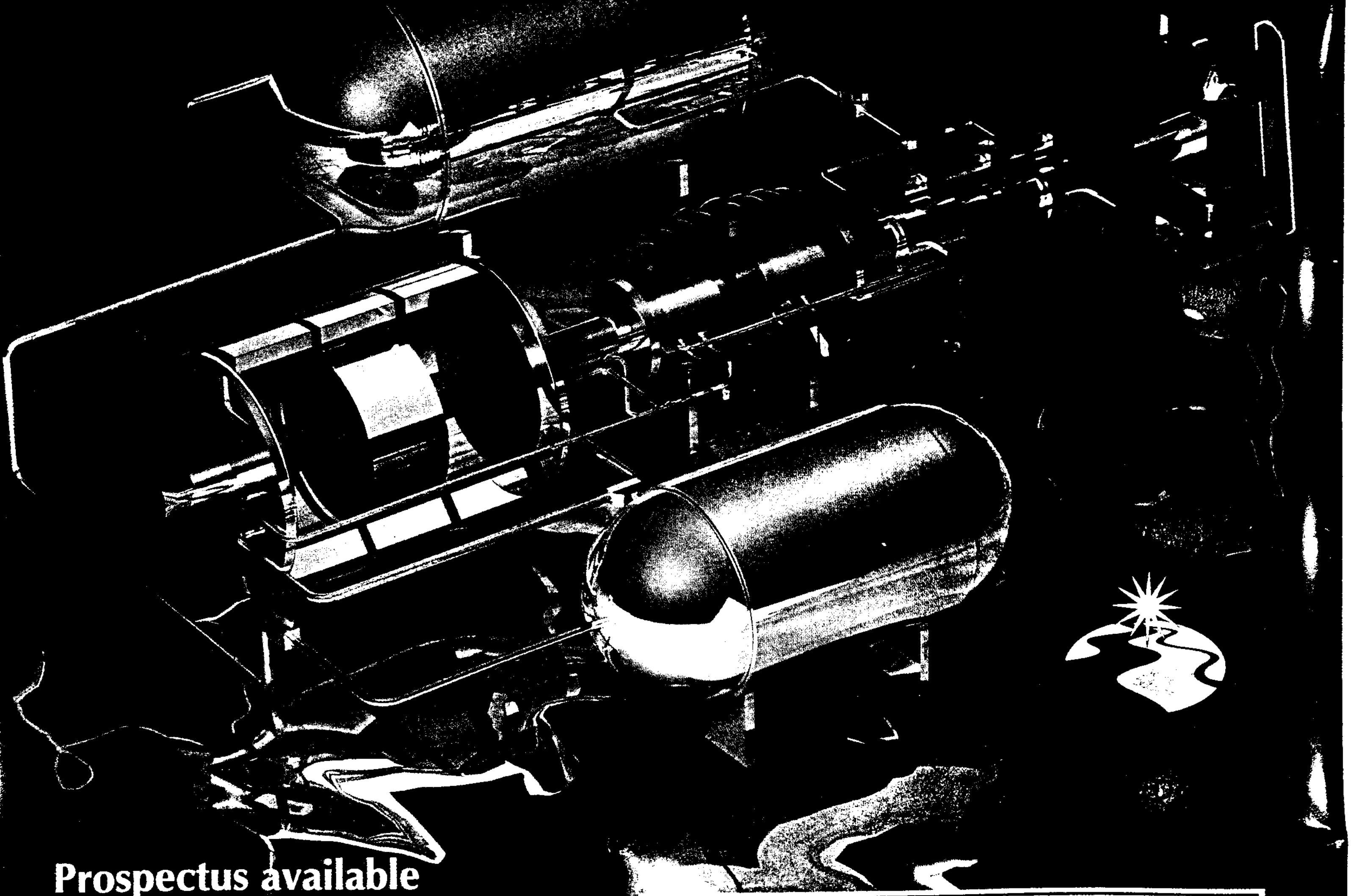
Linear Engine

for global markets

An Australian invention which runs on compressed air from windmills and/or steam generated from solar mirror collectors.

This environmentally friendly engine has excellent prospects for early commercialisation in Remote Area Power Systems (RAPS) applications in the field of renewable energy.

The Linear Engine's exhaust emission of pure, cold air also has commercial applications in air-conditioning, refrigeration and the production of liquid air and industrial gases.



Prospectus available

Fill in the coupon and send to:
Linear Energy Corporation Limited
PO Box 7217 Gold Coast Mail Centre
Bundall 4217, Queensland, AUSTRALIA.
Tel 61 7 5574 1810 or Fax: 61 7 5574 1820
email linearen@OntheNet.com.au
Internet http://www.linearenergy.com.au

Name:
Company:
Address:
Post Code:
Country:
Tel:
Fax:

Prospectus dated 19 November 1996. Copy lodged with the Australian Securities Commission on 12 November 1996.
Applications for shares may only be made on the form attached to the prospectus.

No. 868,500. PATENTED OCT. 15, 1907.

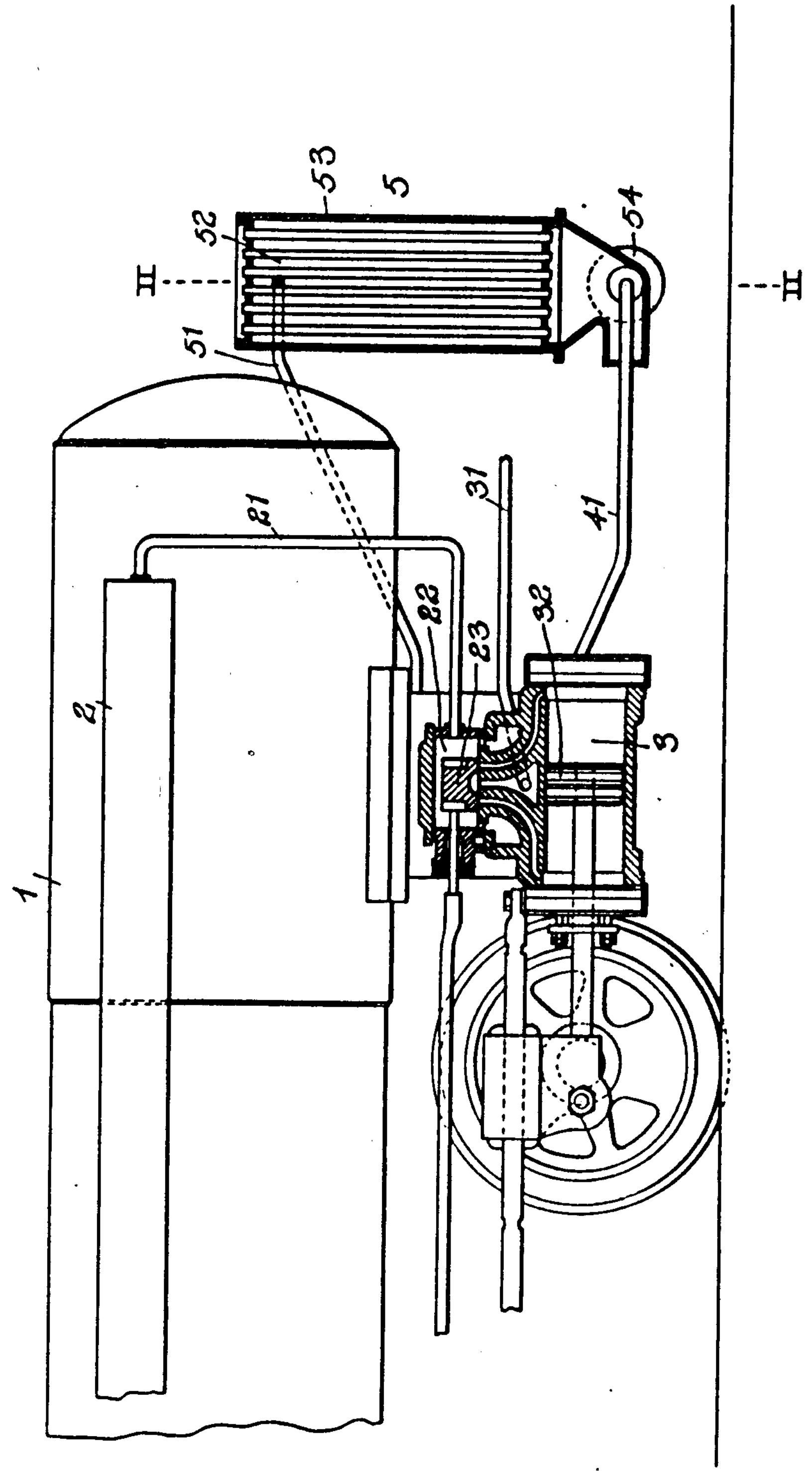
C. B. HODGES.

INTERHEATER FOR COMPOUND COMPRESSED AIR ENGINES.

APPLICATION FILED OCT. 19, 1905.

2 SHEETS—SHEET 1.

FIG. 1.



WITNESSES:
Herbert Bradley.
Fred Kirchner.

Charles B. Hodges INVENTOR
by Christy and Christy
Att'ys.

No. 868,560. PATENTED OCT. 15, 1907.

C. B. HODGES.

INTERHEATER FOR COMPOUND COMPRESSED AIR ENGINES.

APPLICATION FILED OCT. 10, 1904.

2 SHEETS—SHEET 2.

FIG. 2.

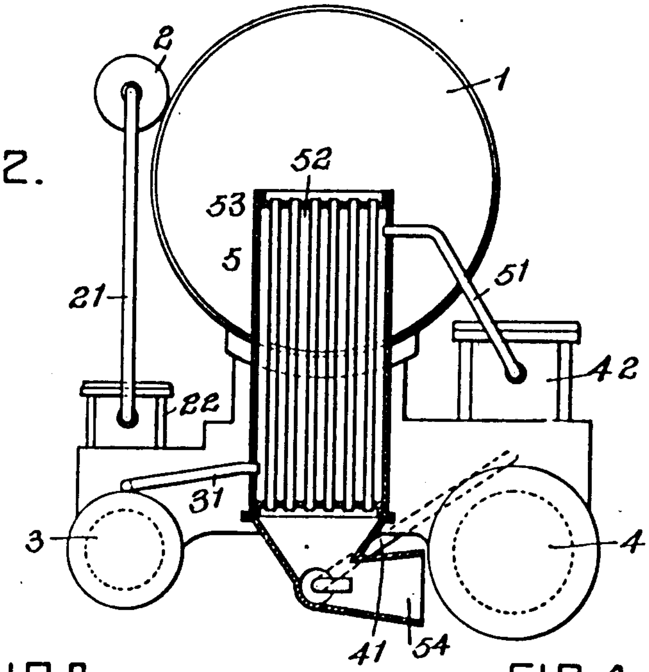


FIG. 3.

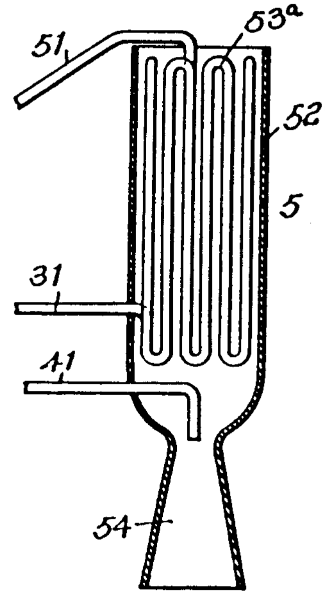
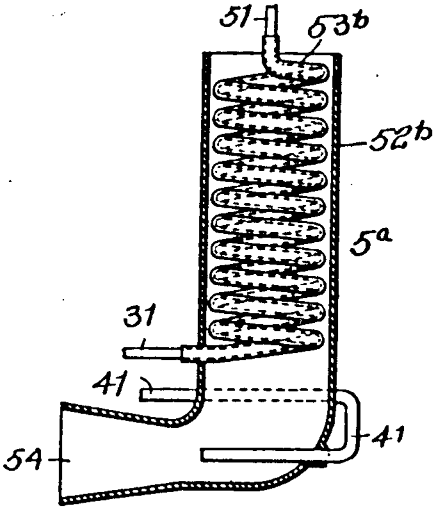


FIG. 4.



WITNESSES:
Herbert Bradley.
Fred Kirchner

Charles B. Hodges INVENTOR
by Christy and Christy
ATT'YS

UNITED STATES PATENT OFFICE.

CHARLES BOWEN HODGES, OF PITTSBURG, PENNSYLVANIA.

INTERHEATER FOR COMPOUND COMPRESSED-AIR ENGINES.

No. 868,560. **Specification of Letters Patent.** **Patented Oct. 15, 1907.**

Application filed October 10, 1904. Serial No. 227,862.

To all whom it may concern:

Be it known that I, CHARLES BOWEN HODGES, residing at Pittsburg, in the county of Allegheny and State of Pennsylvania, a citizen of the United States, have invented or discovered a certain new and useful Improvement in Interheaters for Compound Compressed-Air Engines, of which improvement the following is a specification.

My invention concerns interheaters for compound compressed-air engines, and the object of my improvements is an interheater designed and adapted to take heat from the atmosphere in such quantities as to be efficient in service.

In the accompanying drawings which form part of this specification, Figure 1 shows diagrammatically and in longitudinal elevation a compound compressed-air locomotive engine to which my improvement is applied. In this figure the valve-chest and cylinder at one side of the locomotive and the interheater are shown partly in section. Fig. 2 is a transverse vertical section on the line II II, Fig. 1. Fig. 3 is a vertical sectional view showing my interheater in detail, and illustrating a modification of the form shown in Figs. 1 and 2. Fig. 4 is a view similar to Fig. 3, illustrating a further modification. Parts which are repeated in the several figures bear the same reference numerals in each case.

In the drawings, 1 represents the main storage tank of a compressed-air locomotive, arranged after the manner of and resembling in shape the boiler of a steam locomotive; 2 is the auxiliary reservoir; 3 is the high-pressure cylinder; and 4 the low-pressure cylinder; 5 is the interheater.

From the auxiliary reservoir, 2, a pipe, 21, leads to the high-pressure valve-chest, 22, whence it passes on the appropriate shifting of the valve, 23, to high-pressure cylinder, 3, and drives the piston, 32, therein. Upon the appropriate movement of valve 23, the air (having done its work in cylinder 3) passes from cylinder 3 through a pipe 31 to interheater 5. From interheater 5 the air passes through a pipe, 51, to valve-chest, 42, of low-pressure cylinder 4. The appropriate movement of the valve in valve-chest 42 admits the air into the low-pressure cylinder, where it performs its work in driving the piston contained therein, and whence it escapes on the further shifting of the valve and passes into an exhaust pipe, 41, through which it escapes to the atmosphere. I preferably carry the air through pipe 41 to interheater 5, where it performs the office which I shall presently describe.

The interheater consists in general terms of a receptacle for the compressed air as it passes from the high-pressure cylinder, and before it enters the low-pressure cylinder, such receptacle having a surface of relatively great extent, for the purpose of receiving and imparting to the compressed air contained within it, the heating effect of the atmosphere. It will be understood that this receptacle may be of any suitable or desired construction, and so arranged in relation to the engine that a movement of atmospheric air along its surface will be caused by or during the operation of the engine. I have found it preferable to make this receptacle cylindrical in form, and to furnish it with a plurality of longitudinally extending tubes through which atmospheric air is caused to pass. This is illustrated in Figs. 1 and 2 of the drawings, wherein the receptacle itself is indicated at 53, and the tubular flues for the atmospheric air are indicated at 52. This receptacle being so disposed and arranged that atmospheric air is caused to flow over the surface, and thus to impart a substantial amount of heat to the chilled air contained within it, various means may be employed for causing this flow of atmospheric air over the surface. The drawings show the invention applied to a locomotive engine, and while any desired construction and arrangement of atmospheric heating receptacle may be employed, it is preferred to employ the exhaust from the low-pressure cylinder to produce the draft of air over the heating surface of the receptacle. In Figs. 1 and 2 I have shown a flared orifice, 54, into which the flues 52 open. Into this I conduct, through pipe 41, the exhaust from the low-pressure cylinder, and by causing this exhaust to be projected into the flared orifice 54, I produce the desired draft of atmospheric air through the flues 52 and over the heating surfaces of the receptacle 53.

An alternative construction is shown in Fig. 3, where, in place of a cylindrical receptacle provided with longitudinal flues, the receptacle consists of a coil of pipe, 53^a, arranged within a casing, 52^a, and the draft is caused to flow through this casing. As before, I employ the flared orifice 54, which in this case forms a continuation of the casing 52^a.

In Fig. 4 a further modification is illustrated; the receptacle consists of a fluid-enveloped coil of pipe, 53^b, contained within a casing, 52^b, and so arranged that a current of atmospheric air may be caused to pass through the casing and over the extended surface of the coil. As in Fig. 3, the casing 52^b is continued in a flared orifice, 54, into which the exhaust from the low-pressure cylinder is directed for the purpose of causing a flow of air. The object of the fluid envelop is to equalize the heating effected. It will be understood that, as the engine starts and stops and changes its speed, the amount of cold air flowing from the high-pressure cylinder to be regenerated in the interheater will vary, and accordingly the amount of heat absorbed in the interheater will vary in quantity. By providing a liquid envelop for the receptacle I am able to store the heat of the atmosphere in this liquid envelop, and hold it that it may be available when there is an increase in the flow of cold compressed air. In this case I not only take advantage of the equalizing influence of the liquid envelop, but at the same time I take advantage of the actual heating power of the liquid itself, and this is a matter of considerable moment. While the relative volumes of the liquid which forms the envelop and of the air which passes within the receptacle are very unequal, the number of heat units in a given volume of liquid is immensely greater than in an equal volume of air.

As a certain volume of water contains more heat units than an equal volume of air at the same temperature, by increasing the volume of the liquid envelop, it will not only transmit the heat received from the atmosphere to the compressed air, but will also impart some of its heat to the compressed air, and in this way the heating action of the air is supplemented. If for example the liquid envelop contains 500 lbs. of water at the beginning of a run and the engine moves up a grade using large volumes of compressed air, the latter in its flow to the low pressure cylinder will not only absorb heat units from the air but also serve to take heat units from the envelop reducing the temperature of the envelop. When the engine moves down grade, there will be opportunity for at least a partial restoration to the envelop of normal temperature. In other words this envelop which will not have a temperature above normal atmospheric temperature, acts as a fly wheel to maintain approximately uniform conditions. This liquid envelop may be constructed in any desired manner; as it is illustrated in Fig. 4, it surrounds a coil of pipe in a familiar form of water-jacket.

The flared orifice 54 of the interheater is shown in the several figures of the drawing as directed in several different directions. The direction in which it is pointed is immaterial to my invention, although practical conditions will determine the direction in specific cases.

In describing the construction of my improved apparatus, I have made plain its operation. When the air passes from the high-pressure cylinder of a compound engine, it is greatly reduced in temperature, and since the volume of a body of gas and the pressure which it exerts are dependent upon its temperature, this very low temperature which the air flowing from the high-pressure cylinder possesses, reduces its expansive power, and makes it accordingly less efficient for further work. The interheater serves the purpose of regenerating this air in this sense, that it restores heat to it; and, in so doing, increases its expansive power and makes it more efficient for work in the low-pressure cylinder. In my apparatus the cold compressed air as it passes from the high-pressure cylinder is, in the interheater, subjected to a heating influence, which causes a rise in the temperature, and increases its efficiency; and, since the source of the increase in temperature is the heat of the atmosphere itself, my device besides being simple is economic, and demands little or no attention.

In the drawings I have shown my invention applied to a locomotive engine, because that is the application in which I have found practical operation. I do not, however, limit myself thereto; and it will be understood that the invention is applicable generally to compound compressed-air engines.

I claim herein as my invention.

1. In a compound compressed-air engine in combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a receptacle for compressed air connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, and means for causing a current of air to flow over the surface of the said receptacle operative on the exhaust of air from the low-pressure cylinder, substantially as described.

2. In a compound compressed-air engine, in combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a receptacle for compressed air connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, and a passage for atmospheric air through said receptacle, the exhaust from the low-pressure cylinder being so arranged at the discharge end of said air passage as to draw atmospheric air therethrough, substantially as described.

3. In a compound compressed air engine in combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a receptacle for compressed air connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, passages for atmospheric air through said receptacles, the exhaust from said low-pressure cylinder being arranged to cause a flow of atmospheric air at normal temperature through the passages, substantially as described.

4. In a compound compressed-air engine, the combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a casing arranged to permit the passage of a current of atmospheric air therethrough and provided with a flaring outlet, a receptacle for compressed air arranged within said casing and connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, the exhaust from the low-pressure cylinder being arranged to discharge into the flaring outlet of said casing, substantially as described.

5. An interheater for a compound compressed-air engine which consists of a receptacle receiving air from the high-pressure cylinder and delivering air to the low-pressure cylinder, said receptacle being provided with a surrounding fluid envelop, such fluid-enveloped surface being of relatively great extent and arranged and adapted to absorb heat from the atmosphere, substantially as described.

In testimony whereof, I have hereunto set my hand.

CHARLES BOWEN HODGES.

Witnesses:
ALICE A. TRILL.
BAYARD H. CHRISTY.

C. B. HODGES.

METHOD OF OPERATING COMPOUND COMPRESSED AIR ENGINES.

APPLICATION FILED JUNE 11, 1909.

953,384. Patented Mar. 29, 1910.

2 SHEETS—SHEET 1.

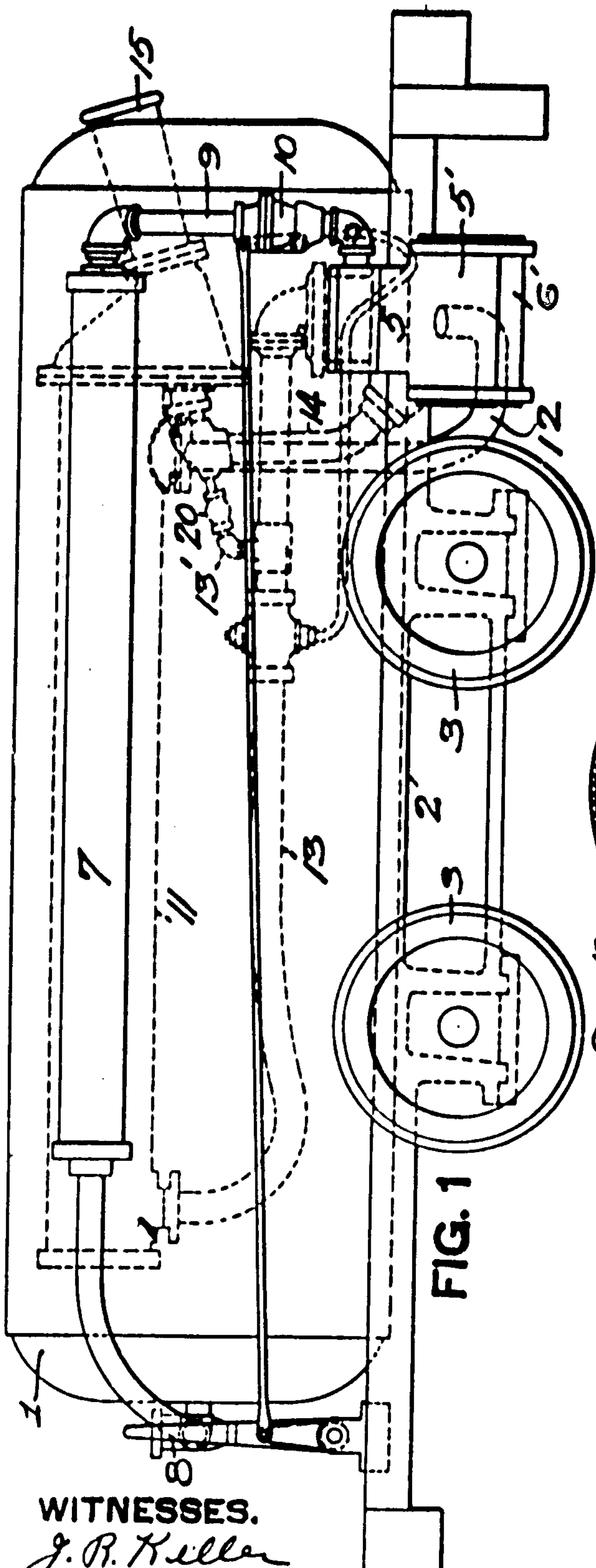


FIG. 1

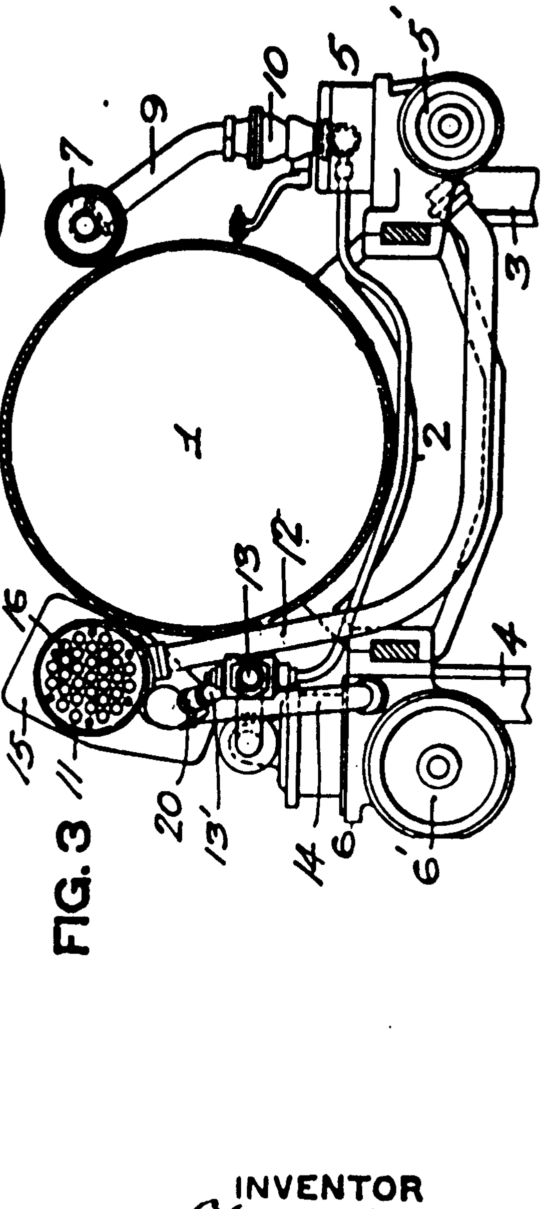


FIG. 3

WITNESSES.
J. R. Keller
Robert C. Totten

INVENTOR
Charles B Hodges
By Kay & Totten
attorneys

C. B. HODGES.

METHOD OF OPERATING COMPOUND COMPRESSED AIR ENGINES.

APPLICATION FILED JUNE 11, 1909.

953,334. Patented Mar. 29, 1910.

2 SHEETS—SHEET 2.

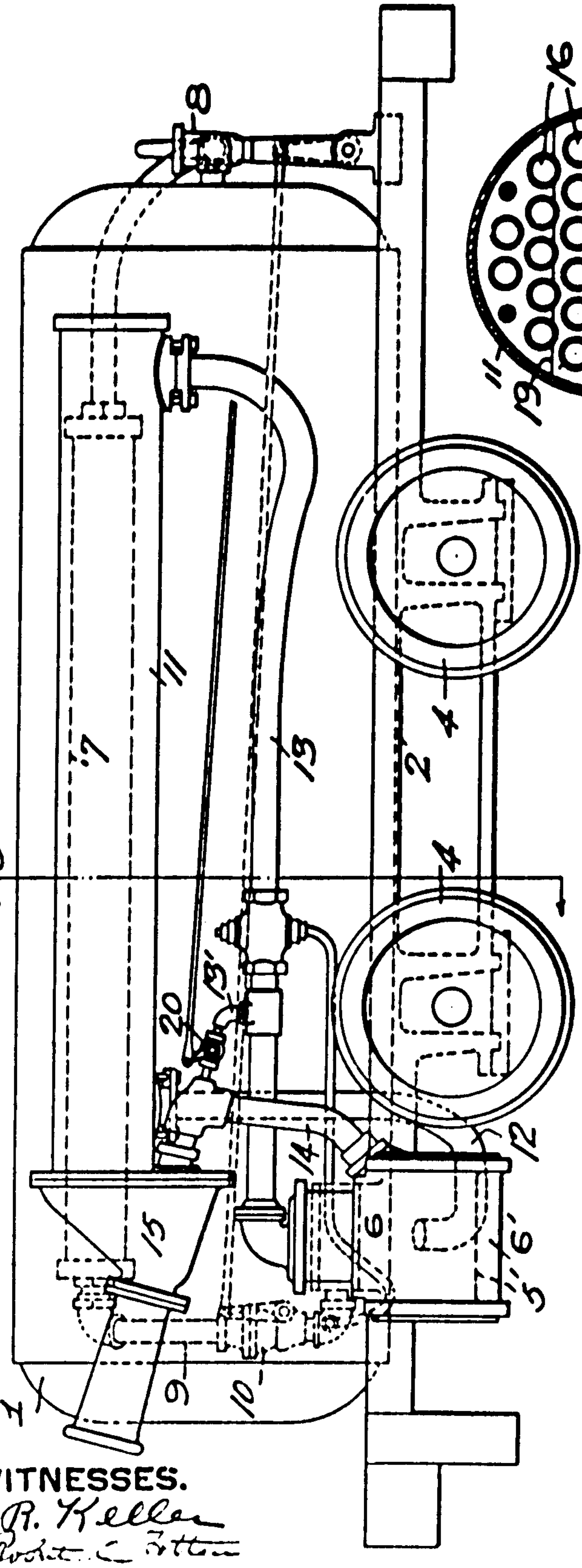


FIG. 2

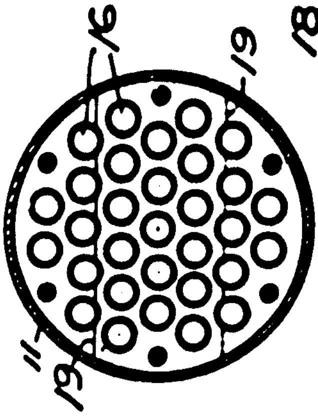


FIG. 5

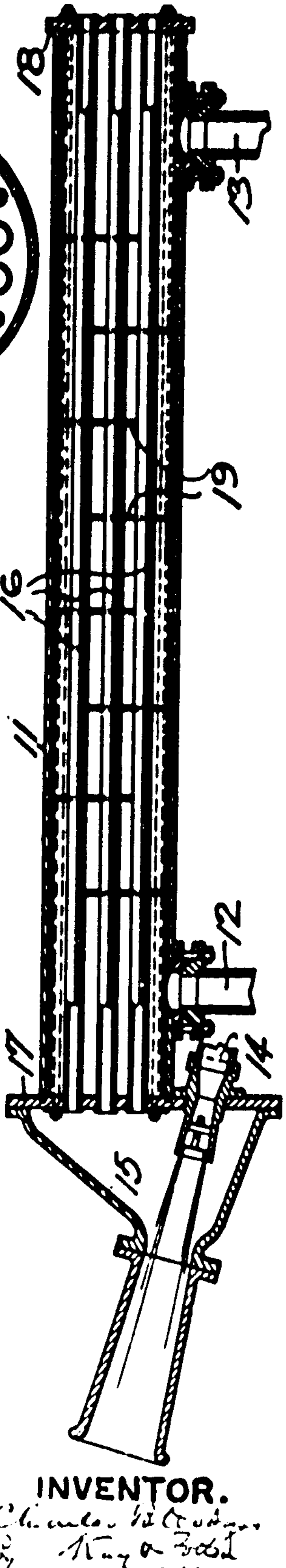


FIG. 4

WITNESSES.

J. R. Keller
Robert C. Totten

INVENTOR.

Charles B. Hodges
By Kay & Totten
Attorneys

UNITED STATES PATENT OFFICE.

CHARLES B. HODGES, OF PITTSBURG, PENNSYLVANIA, ASSIGNOR TO H. K. PORTER COMPANY, OF PITTSBURG, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA.

METHOD OF OPERATING COMPOUND COMPRESSED-AIR ENGINES.

953,334. Specification of Letters Patent. Patented Mar. 29, 1910.

Application filed June 11, 1909. Serial No. 501,641.

To all whom it may concern:

Be it known that I, CHARLES B. HODGES, a resident of Pittsburg, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Methods of Operating Compound Compressed-Air Engines; and I do hereby declare the following to be a full, clear, and exact description thereof.

My invention relates to methods of operating compound compressed air engines, its object being to so operate the same as to obtain increased power from the compressed air.

It consists, generally stated, in operating such compressed air engines by carrying the compressed air through and expanding it in one cylinder and thereby reducing it below lowest atmospheric temperature, re-heating the exhaust air when confined and at low pressure by extended exposure thereof to air heating at atmospheric temperature and thereby increasing the volume thereof and carrying the re-heated air through a low pressure cylinder.

The invention also includes the utilization of the compressed air in such way as to obtain approximately the proper balance as between the two cylinders of a compound compressed air engine so that the power generated in each will be approximately the same according to the pressure of the air as utilized in the respective cylinders.

In the accompanying drawings Figure 1 is a side view of a locomotive engine adapted for the use of the invention, and Fig. 2 is a side view partly broken away on the opposite side thereof; and Fig. 3 is a cross section on the line 3—3 Fig. 2, and Fig. 4 is a longitudinal section partly broken away of the preferred form of the interheater and Fig. 5 is a cross section of said interheater.

To accomplish the above results in the apparatus best adapted for the purpose and as applied to, for example, a locomotive engine, I employ the main air reservoir 1 supported on a suitable locomotive truck or underframe 2 mounted on the driving wheels 3 and 4 on the two sides of the locomotive. On the high pressure side, as shown in Fig. 1, the high pressure engine is shown at 5 connected up to the wheels 3, while on the other side the low pressure engine is shown at 6 connected to the wheels 4. The auxiliary reservoir 7 is supported on the main reservoir 1 and air is fed thereto from the main reservoir through a suitable reducing valve 8, bringing the air to proper pressure for entrance to the valve box of the high pressure cylinder 5'. The pipe 9 leads to the high pressure cylinder and has located therein the operating or throttle valve 10.

From the high pressure cylinder 5' the air passes to the air inter-heater 11 through the pipe 12 and from the same through the pipe 13 to the valve box of the low pressure cylinder 6', the air escaping therefrom through the pipe 14 which preferably exhausts into the nozzle 15 of the air interheater 11 to induce a draft through the same for the re-heating of the air discharged from the high pressure cylinder. The best results are obtained when the air enters the high pressure cylinder at a pressure of about 250 pounds and discharges therefrom at a pressure of about 50 pounds, and is raised by reheating by atmospheric heating to about four volumes of the original compressed air, so that the low pressure cylinder has a cubical contents of about four times that of the high pressure cylinder; for example, the high pressure cylinder having a diameter, say, of about 5 inches, and the low pressure cylinder having a diameter of about 10 inches.

Any suitable receptacle for reheating the compressed air by the reheating action of atmospheric air between the high pressure cylinder and low pressure cylinder may be employed, and the travel of the atmospheric air over the surfaces of such receptacle can be induced in any suitable way. The preferred form of inter-heater is illustrated in Figs. 2 and 3, being supported in horizontal position on the side of the main reservoir, extending for practically the full length thereof, being of small diameter and relatively great length to provide for a relatively strong or violent draft of air through the tubes thereof for re-heating of the compressed air. In the best form, as heretofore used when the engines are ten inches stroke and the cylinders five and ten inches in diameter respectively, the inter-heater is about 7 feet long, 8 inches in inside diameter, and is filled with a large number of tubes, for example, about thirty 1-inch tubes, as at 16, seated in the end walls 17, 18 of the inter-heater, the inter-heater having a suitable series of baffles 19 between the tubes 16 so as to cause the compressed air to be re-heated to travel in circuitous course around the re-heating tubes. The atmospheric air is carried through the tubes 16 by the draft induced within the exhauster nozzle 15, such as by the discharge of the exhaust air from the low pressure cylinder through the pipe 10. Air under pressure may also be employed for inducing the draft such as by the pipes 19 leading from the pipe 13, and controlled by the valve 20.

In the practice of the invention with the apparatus above described, the compressed air is stored at a relatively high pressure, say, about 800 pounds, within the main reservoir 1 and it is maintained within the auxiliary reservoir 7 at the desired pressure for the operation of the engine, say about 250 pounds. Upon the operation of the throttle valve 10 it passes into the high pressure cylinder 5' and does work therein, escaping therefrom at a relatively low pressure, for example, in the best practice at a pressure of about 50 pounds. The sudden and rapid expansion of the air within said high pressure cylinder causes a violent drop in the temperature of the air, bringing it below lowest atmospheric temperature *i. e.*, reducing it far below the temperature of the surrounding atmosphere. For example, if it enters at average atmospheric pressure of 60° Fahrenheit, the air passes therefrom at a temperature below lowest atmospheric temperature, the reduction in temperature being usually about 140° F., so that it is brought to a temperature of about 80° below zero F. At such low temperature the volume of air is insufficient to fill the low pressure cylinder at a pressure of 50 pounds and if utilized at such low temperature the apparatus will be quickly clogged through the gathering of frost, freezing of the lubricant, and from other causes. I therefore discharge the exhaust from the high pressure cylinder into a suitable receptacle and utilize the atmospheric air for re-heating the compressed air when so confined by carrying the atmospheric air over the exposed surfaces of such receptacle, for example, through the tubes of the inter-heater 11, preferably using for this purpose the exhaust air from the low pressure cylinder. By such exhaust a violent draft of atmospheric air is carried through the tubes of the inter-heater, and as the compressed air travels around said tubes it is re-heated by the atmospheric air and raised thereby approximately to or approaching atmospheric temperature, and it is thereby increased in volume, a sufficient volume for utilization within the low pressure cylinder of relatively greater cubic contents than the high pressure cylinder being obtained.

In practice I find that by making the low pressure cylinder about four times the cubical contents of the high pressure cylinder, as above stated, I am enabled to utilize the compressed air therein at the pressure of 50 pounds per square inch and generate about the same power as that generated within the high pressure cylinder, so as to maintain the proper balance of power in the two cylinders as applied to the driving shaft or shafts of the locomotive or other engine. For example, where the high pressure air is reduced in the high pressure cylinder from 250 to 50 pounds per square inch, the unbalanced pressure per square inch utilized in such cylinder is 200 pounds, while in the low pressure cylinder at 50 pounds and four times the piston area the total pressure exerted is the same. Of course this may be varied as found desirable, but within practicable limits the expansion within the high pressure cylinder is such as to reduce the temperature of the air at least 100° F., and the low pressure cylinder is made of such size as to utilize the compressed air according to the relative reduction in pressure, and the air is re-heated within the inter-heater to bring it to the proper volume according to the relative sizes of the high pressure and low pressure cylinders. By thus providing for the rapid expansion of the high pressure air and providing by atmospheric re-heating for the necessary increase of volume of the expanded air to provide for its utilization within the low pressure cylinder, practically all of the power to be generated from the compressed air is obtained and I am enabled to utilize atmospheric heating through the carrying of the expanded compressed air through the inter-heater in such way as to give proper exposure to the atmospheric air for the re-heating thereof, and such re-heating is obtained without the expenditure of power other than that sufficient to expose the compressed air to proper atmospheric re-heating between the high pressure cylinder and the low pressure cylinder, and at the same time to balance the power obtained so as to utilize the force generated upon the same driving shaft and balance that power in the operation of the engine, so utilizing practically all the power to be generated from the compressed air.

In order to insure a sufficient draft through the inter-heater to re-heat the air entering the same from the high pressure cylinder and increase its volume to the full extent to obtain the desired power therefrom in the low pressure cylinder, instead of or in addition to the use of the exhaust air from the low pressure cylinder, I may introduce a jet of air under pressure into the nozzle of the inter-heater: for example, by means of the pipe 13' taken from the pipe 13 as above described.

The general apparatus employed for the

practice of the method set forth herein is disclosed in Letters Patent No. 868,560, granted to me October 15, 1907.

The special method of inducing a current of air at atmospheric temperature over the surface of the confining receptacle by a jet of air at as high pressure as that entering the low pressure cylinder, for example as that passing through the pipe 13', forms the subject matter of a separate application filed by me of even date herewith, Serial No. 501,642.

The specific apparatus illustrated in this application and involving the employment of an air interheater having a long contracted body of small diameter filled with a large number of tubes of small diameter and a pipe carrying air from the pipe leading to the low pressure cylinder for inducing a draft over the exposed surface of the air interheater, forms the subject matter of an application filed by me of even date herewith, Serial No. 501,643.

What I claim is:

1. The method of operating compressed air engines, consisting in carrying the air at high pressure through and expanding it in one cylinder and thereby reducing it below lowest atmospheric temperature, re-heating the exhaust air from said cylinder when confined by extended exposure to air heating at atmospheric temperature and thereby increasing the volume thereof and its capacity to generate power, and carrying the re-heated air through a low pressure cylinder.

2. The method of operating compressed air engines, consisting in carrying air at high pressure through one cylinder and thereby reducing it below atmospheric temperature, confining such air within a receptacle and by a jet of air under pressure inducing a current of air at atmospheric temperature over the exposed surface of such receptacle and thereby reheating and increasing the volume of such exposed air, and carrying the reheated air through a low pressure cylinder.

3. The method of operating compressed air engines, consisting in carrying the air at high pressure through and expanding it in one cylinder and thereby reducing it below lowest atmospheric temperature, re-heating the exhaust air from said cylinder when confined by extended exposure to air heating at atmospheric temperature and thereby increasing the volume thereof, and carrying the re-heated air through a low pressure cylinder, and so discharging the exhaust therefrom as to induce a draft over the exposed surfaces of the receptacle confining the exhaust air from the high pressure cylinder.

4. The method of operating compressed air engines, consisting in carrying the air at high pressure through and expanding it in one cylinder and thereby reducing it below lowest atmospheric temperature and reheating the exhaust air when confined by extended exposure thereof to air at atmospheric temperature and thereby increasing it to the necessary volume to generate substantially like power within another cylinder of greater cubical contents and carrying such re-heated air through such low pressure cylinder.

In testimony whereof, I the said CHARLES B. HODGES have hereunto set my hand.

CHARLES B. HODGES.

Witnesses:
ROBERT C. TOTTEN,
J. F. WILL.

C. B. HODGES.

METHOD OF OPERATING COMPOUND COMPRESSED AIR ENGINES.

APPLICATION FILED JUNE 11, 1909.

953,335. Patented Mar. 29, 1910.

3 SHEETS—SHEET 1.

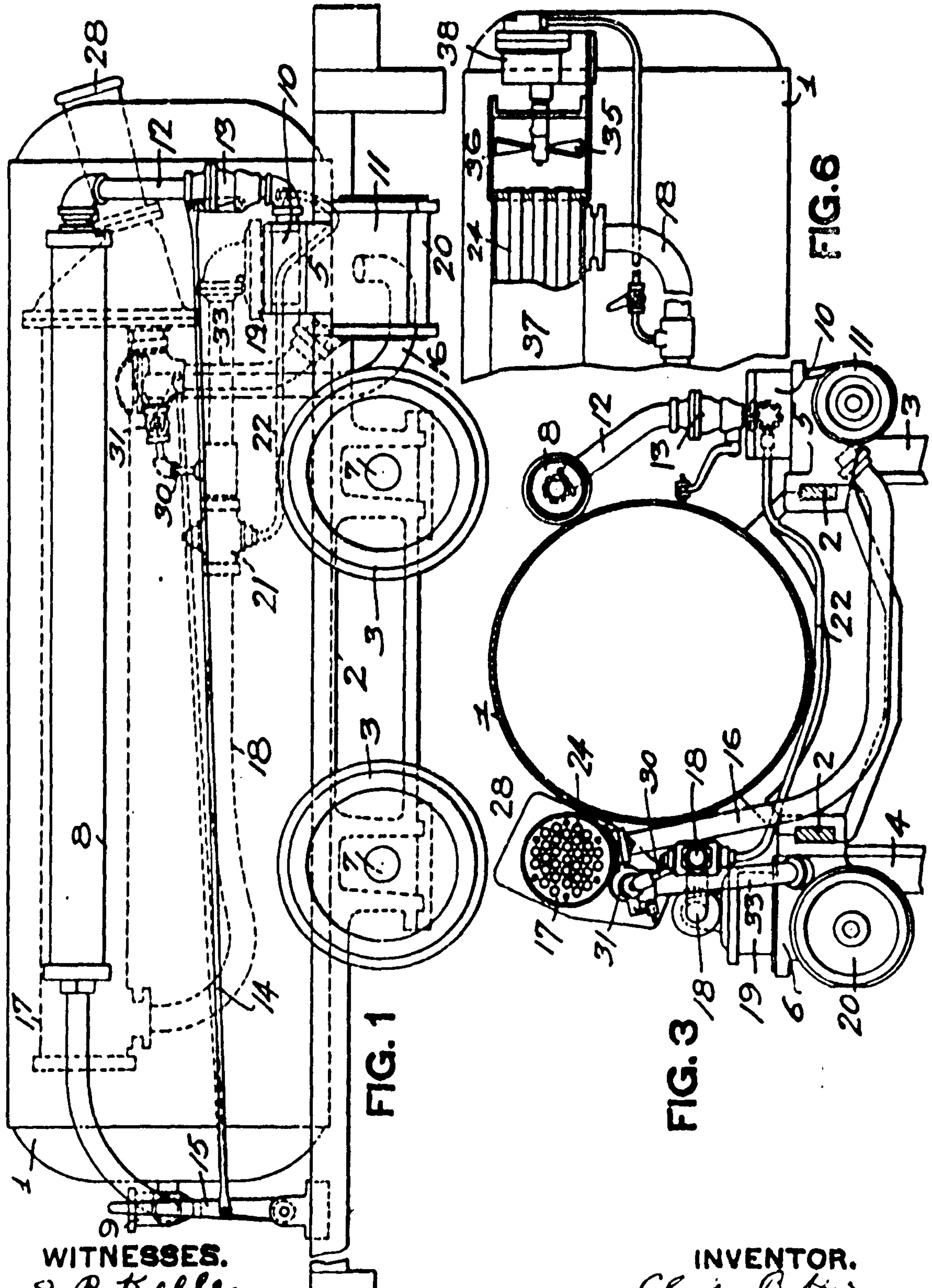


FIG. 1

FIG. 3

FIG. 6

WITNESSES.

J. R. Keller

Robert C. Totten

INVENTOR.

Charles B. Hodges

By Kay & Totten

attorneys

C. B. HODGES.

METHOD OF OPERATING COMPOUND COMPRESSED AIR ENGINES.

APPLICATION FILED JUNE 11, 1909.

953,383. Patented Mar. 29, 1910.

2 SHEETS—SHEET 2.

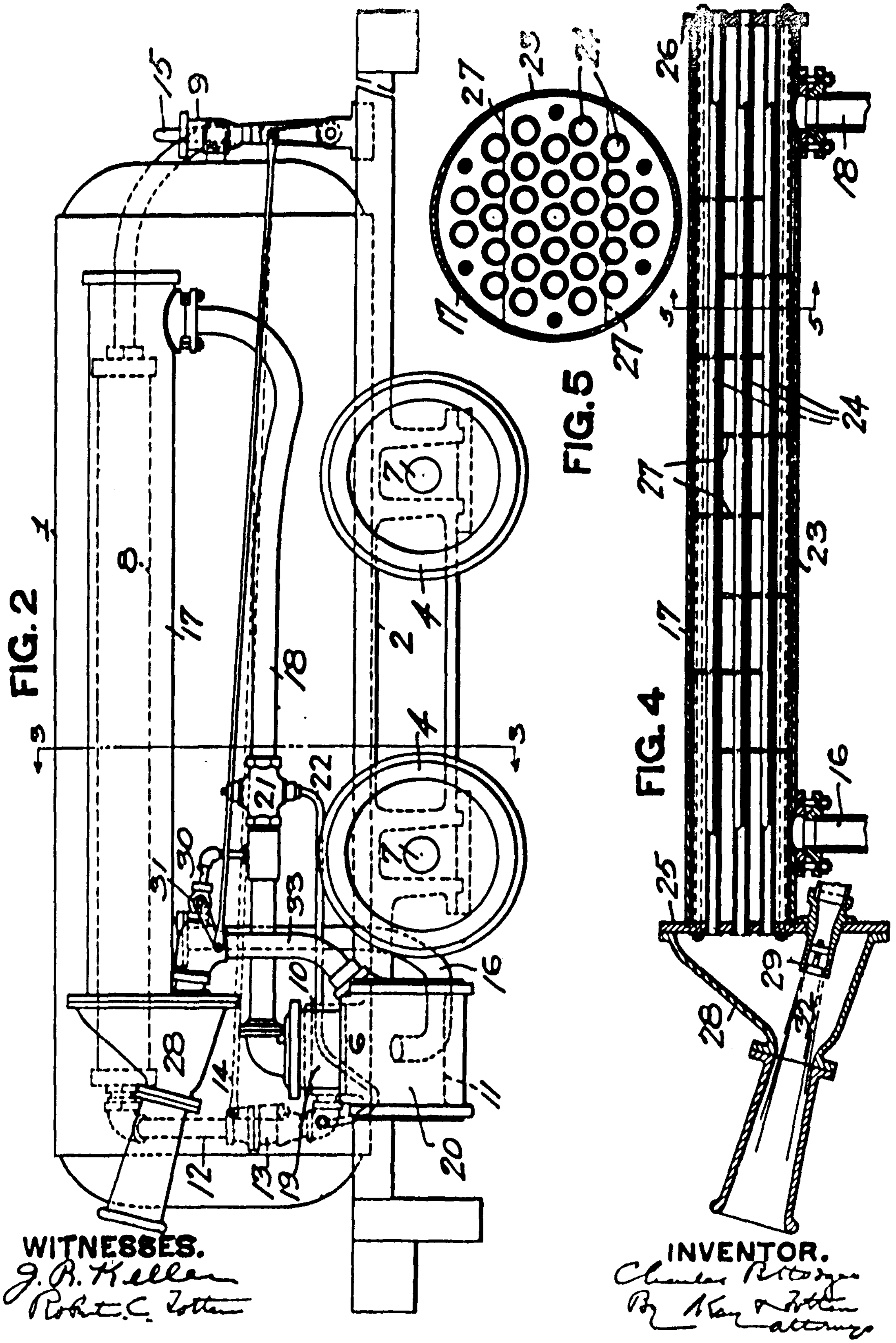


FIG. 2

FIG. 5

FIG. 4

WITNESSES.

J. R. Keller

Robert C. Totten

INVENTOR.

Charles B. Hodges

By Kay & Totten

attorneys

UNITED STATES PATENT OFFICE.

CHARLES B. HODGES, OF PITTSBURG, PENNSYLVANIA, ASSIGNOR TO H. K. PORTER COMPANY, OF PITTSBURG, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA.

METHOD OF OPERATING COMPOUND COMPRESSED-AIR ENGINES.

953,335. Specification of Letters Patent. **Patented Mar. 29, 1910.**

Application filed June 11, 1909. Serial No. 501,642.

To all whom it may concern:

Be it known that I, Charles B. Hodges, a resident of Pittsburg, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Methods of Operating Compound Compressed-Air Engines; and I do hereby declare the following to be a full, clear, and exact description thereof.

My invention relates to a method of operating compound compressed air engines, its object being to so operate the same as to insure the maintenance of the surface of the air inter-heater in proper condition for the proper reheating of the air expanded within the high pressure cylinder and insure the proper operation of the engine.

It consists, generally stated, in carrying the compressed air at high pressure through and expanding it within the high pressure cylinder and thereby reducing it below atmospheric temperature, confining such exhaust air within a receptacle having extended exposed surfaces and reheating the same by inducing over such exposed surfaces a violent current of air at atmospheric temperature sufficient to scour from or prevent the formation of frost on such surfaces, thereby reheating and increasing the volume of such exhaust air and carrying the reheated air through the low pressure cylinder.

It also consists of certain other improvements as hereinafter set forth and claimed.

In the accompanying drawing Figure 1 is a side view of a locomotive engine adapted for the use of the invention; Fig. 2 is a side view partly broken away on the opposite side thereof; Fig. 3 is a cross section on the line 3—3 Fig. 2; Fig. 4 is an enlarged longitudinal section of the inter-heater and Fig. 5 is a cross section thereof; Fig. 6 is a detail view of one end of the inter-heater showing other means of inducing the violent current through the same.

In the original development of the compound compressed air engine such as illustrated in Letters Patent No. 868,560 granted to me October 15th, 1907, difficulty was encountered in the gathering of frost upon the exposed surfaces of the inter-heater, and as such frost acted as a non-conductor it prevented the rapid reheating of the compressed air after it was expanded in the high pressure cylinder. This frost also tended to clog and close the tubes of the inter-heater and so reduce the amount of air carried through the tubes and diminish the reheating action of the atmospheric air and as the compressed air within the inter-heater was at a very low temperature, ordinarily entering the same 100 or more degrees F. below atmospheric temperature, the frost covering the tubes of the inter-heater would gradually increase in thickness so as to almost close the same. By the present invention I am enabled to overcome this difficulty and provide for the successful operation of the engine even where the surrounding atmosphere is of very low temperature, in fact below zero F. The apparatus best adapted for the practice of the invention is illustrated in the accompanying drawings as applied to a locomotive, having the main air reservoir 1 supported on suitable locomotive truck or under-frame 2 mounted on the driving wheels 3 and 4 on two sides of the locomotive.

On the high pressure side as shown in Fig. 1 the high pressure engine is shown at 5 connected up to the wheels 3, while on the other side the low pressure engine is shown at 6 connected up to the wheels 4, said wheels being secured to the axles 7. The auxiliary reservoir 8 is supported on the main reservoir 1 and air is fed thereto from the main reservoir through a suitable reducing valve 9 bringing the air to proper pressure for entrance to the valve chest 10 of the high pressure cylinder 11. The pipe 12 leads to the high pressure cylinder and located therein is the operating or throttle valve 13 which is connected by the rod 14 to the throttle lever 15. The pipe 16 leads from the exhaust of the high pressure cylinder 11 to the inter-heater 17 and the pipe 18 leads from the inter-heater to the valve chest 19 of the low pressure cylinder 20 from which cylinder the air exhausts. In the preferred construction I locate in the pipe 18 a stop valve 21 to hold the air within the inter-heater upon the closing of the throttle valve, said stop valve being actuated by the fluctuations of pressure in pipe 12 transmitted through pipe 22, as described in application for patent filed by me October 26, 1908, Serial No. 459,612. The preferred form of inter-heater is illustrated in Figs. 2, 4 and 5, being supported in horizontal position on the side of the main reservoir and extending for practically the full length thereof and being of small diameter and relatively great length, and is filled with a large number of small tubes to provide for a relatively strong or violent draft of air through the tubes thereof for reheating the compressed air. For example, in practical use I have found that with the cylinders 5 and 10 inches in diameter by 10 inches stroke, the best form of inter-heater is made of a casing 23 about 7 feet long and about 8 inches inside diameter, this inter-heater being filled with a large number of tubes 24 extending for the full length of the inter-heater seated in the end walls 25, 26 thereof, the tubes being of small diameter, for example, about 30 tubes 1-inch diameter being employed. I also prefer to employ within the inter-heater a suitable series of baffles 27 between the tubes 24 so as to cause the compressed air to be reheated to travel in circuitous course around said reheating tubes. To induce the draft or current of atmospheric air through the inter-heater tubes I may employ different means, for example, in Fig. 2 I have illustrated the apparatus where air under pressure is utilized to induce the draft through the inter-heater. In such case I form at the exhaust end of the inter-heater the nozzle 28, and entering the same is the air jet 29, this jet being connected up to any part of the apparatus from which air under pressure can be drawn.

I prefer to draw the air for inducing the draft from the pipe 18 between the stop valve 21 and the valve chest 19 of the low pressure cylinder, as in this way said stop valve in preventing the escape of compressed air from the inter-heater upon the closing of the main throttle valve also cuts off the air from the air jet 29, there being no escape of air therefrom except when the engine is in operation. To this end I employ the pipe 30 leading from the pipe 18 and having located therein the valve 21 controlling the amount of air escaping from the air jet pipe, and to obtain a stronger inducing current the air jet is of annular form as shown at 32, for example being formed of a ring pipe with a series of jet orifices. To induce the draft through the inter-heater I may also utilize the exhaust from the low pressure cylinder as illustrated in Fig. 2, employing the same either alone or in addition to the air under pressure entering through the pipe 30. In such case the exhaust pipe 33 leads from the low pressure cylinder 20 and discharges into the nozzle 28 of the inter-heater and may communicate with the pipe 30 supplying air under pressure. This provides for the use both of the exhaust air from the low pressure cylinder and of air under pressure, so insuring the formation of a sufficiently violent draft for the scouring of the tubes of the inter-heater as hereafter described. For the same purpose I may also employ an independent fan for inducing the draft through the inter-heater as illustrated in Fig. 6. In this case the fan 35 is located within the tubular extension 36 of the inter-heater 37 at the discharge end thereof and the fan is illustrated as driven by a suitable air motor or turbine 38 operated by air under pressure drawn from any suitable part of the apparatus, such for example, as from the pipe 18 between the inter-heater and the low pressure engine.

In the practice of the invention with the apparatus above described, the compressed air is stored at relatively high pressure, usually about 800 pounds, within the main reservoir 1, and it is maintained within the auxiliary reservoir 8 at the desired pressure for the operation of the engine, say, at about 250 pounds. Upon the operation of the throttle valve 13 the air passes to the cylinder 11 of the high pressure engine and generates power therein, escaping therefrom at a relatively low pressure, for example, in the best practice at a pressure of about 50 pounds.

The sudden and rapid expansion of the air within the high pressure cylinder causes a violent drop in the temperature of the air, this in turn contracting the same and reducing its volume. For example the air enters the high pressure cylinder at 60° F., and it passes therefrom at a temperature far below atmospheric temperature, the reduction in temperature being usually about 140° F. so that it is brought to a temperature of about 80° below zero. If the air were allowed to enter the low pressure cylinder at this temperature such cylinder would have to be smaller or the pressure less, and in either case the amount of work done in the low pressure cylinder would be much reduced, the size of the cylinder or the pressure of the air being reduced approximately one third. By the passage of the air through the interheater as above described the temperature is restored as such pressure is increased in volume so that I am enabled to obtain the same power in the low pressure cylinder which would have been obtained had no drop in temperature occurred. The difference between the temperature of the exhaust air when it leaves the high pressure engine and atmospheric temperature is so great that it quickly causes condensation of moisture carried in the atmosphere which forms as a coating of frost over the exposed surfaces of the inter-heater, such as within the tubes 24 thereof, and as above stated this frost coating serves as a non-conductor and prevents the full reheating action of the atmospheric air passing through the inter-heater, and gradually gathers so that unless removed it will clog and partially close the tubes thereof so reducing the current of air carried therethrough. To keep the tubes of the inter-heater clear from frost and maintain the full action of the atmospheric reheating I induce a very violent draft through the tubes of the inter-heater by the suction or forcing action obtained in any suitable way, such as by air under pressure as shown in Fig. 2, or by the exhaust air from the low pressure cylinder as shown in said figure, or both, or by means of the fan as shown in Fig. 6. Such violent draft of atmospheric air through the tubes of the inter-heater acts to scour over the surfaces thereof on account of the large amount of atmospheric air carried through the small tubes gives a sufficient reheating of the compressed air within the interheater to prevent the formation of frost on the exposed surfaces of such tubes and to scour off any such frost in case it is formed therein, so keeping the tubes of the inter-heater clear from frost and enabling the air carried therethrough to impart its full reheating action to the compressed air confined within the inter-heater. I have found that by providing such violent scouring draft through the tubes of the inter-heater I am enabled to keep such tubes clear from frost even when operating the engine at atmospheric temperatures considerably below zero F., and thus obtain the efficient operation of the engine under such extreme conditions. Where the exhaust from the low pressure engine is insufficient for this purpose it may be supplemented as above described, by the use of compressed air, and the amount of air under pressure used controlled by the valve 31 within the air jet pipe 30 leading from the pipe 16 between the inter-heater and the low pressure cylinder. As through the stop valve 21 in said pipe the escape of air from the inter-heater is prevented upon the closing of the main throttle valve no air under pressure is wasted for the operation of the inter-heater when the engine is not in operation but it is automatically fed to the air jet as soon as the throttle valve is open and the stop valve is opened to admit air from the inter-heater to the low pressure engine.

The general method of operating compressed air engines in which the air at high pressure is carried through one cylinder and thereby reduced below highest atmospheric temperature and the exhaust air therefrom is reheated when confined by extended exposure to air at atmospheric temperature and is then carried through a low pressure cylinder, and the specific methods in which exhaust air from the low pressure cylinder while still under pressure is discharged to induce a draft over the exposed surface of the interheating receptacle, form the subject matter of application filed by me of even date herewith Serial No. 501,641. The apparatus for producing a draft over the exposed surface of the interheater by means of a fan, as illustrated in this application, forms the subject matter of an application filed by me of even date herewith Serial No. 501,640. The construction of the interheater and the connections taken from the pipe leading to the low pressure cylinder for providing air for inducing a draft over the exposed surface of the interheater, form the subject matter of an application filed by me of even date herewith Serial No. 501,643.

What I claim is:

1. The method of operating compound compressed air engines, consisting in carrying the compressed air at high pressure and expanding it within one cylinder and thereby reducing it below atmospheric temperature, confining such exhaust air from said cylinder within a receptacle and inducing over the exposed surfaces of said receptacle a violent current of air at atmospheric temperature sufficient to scour from or prevent the formation of frost on the exposed surfaces of said receptacle and thereby reheating and increasing the volume of such exhaust air and its capacity to generate power, and carrying the reheated air through a low pressure cylinder.

2. The method of operating compound compressed air engines, consisting of carrying the compressed air through and expanding it within one cylinder and thereby reducing it below atmospheric temperature, confining such air within a receptacle having a series of tubes passing through the same and inducing a violent current of air at atmospheric temperature through the tubes of such receptacle sufficient to scour from or prevent the formation of frost therein, thereby reheating and increasing the volume of such exhaust air and carrying the reheated air through a low pressure cylinder.

3. The method of operating compressed air engines, consisting in carrying the air at high pressure through one cylinder, confining the exhaust air therefrom within a receptacle having extended exposed surfaces and then through a low pressure cylinder, and inducing a current of air at atmospheric temperature over the surfaces of the confining receptacle by a jet of air at as high pressure as that entering the low pressure cylinder.

In testimony whereof, I the said Charles B. Hodges have hereunto set my hand.

CHARLES B. HODGES.

Witnesses:
Robert C. Totten,
J. F. Will.

C. B. HODGES.
COMPRESSED AIR ENGINE.
APPLICATION FILED JUNE 11, 1909.

[illegible],

Patented Mar. 29, 1910.
3 SHEETS—SHEET 1.

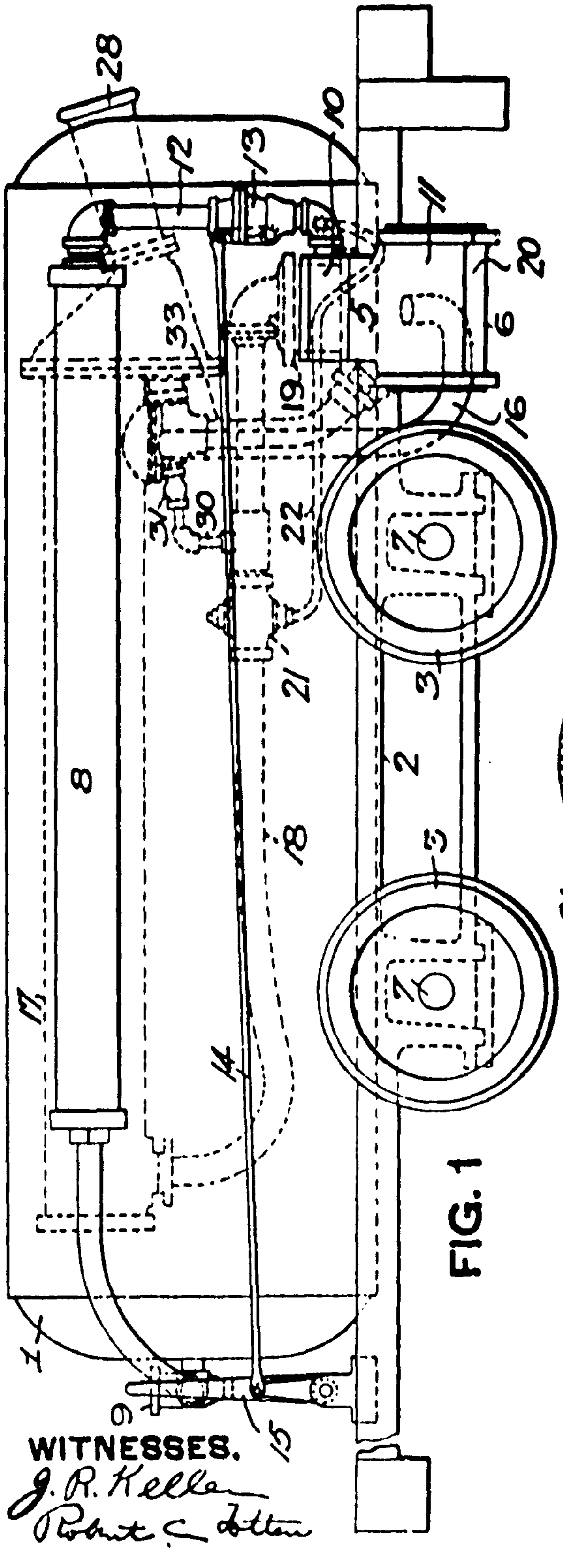


FIG. 1

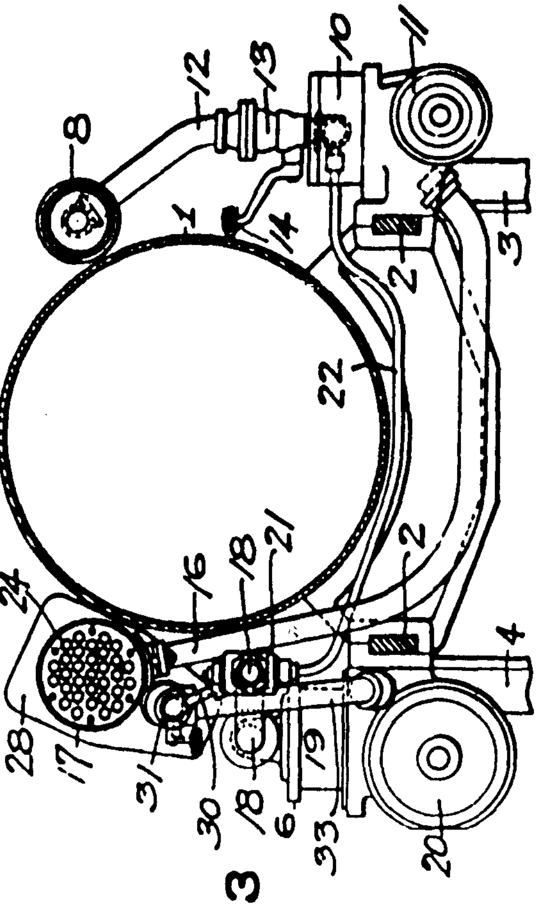


FIG. 3

WITNESSES.
J. R. Keller
Robert C. Totten

INVENTOR.
Charles B. Hodges,
By King & Totten
attorneys

C. B. HODGES.

COMPRESSED AIR ENGINE.

APPLICATION FILED JUNE 11, 1909.

953,888.

Patented Mar. 29, 1910.

2 SHEETS—SHEET 2.

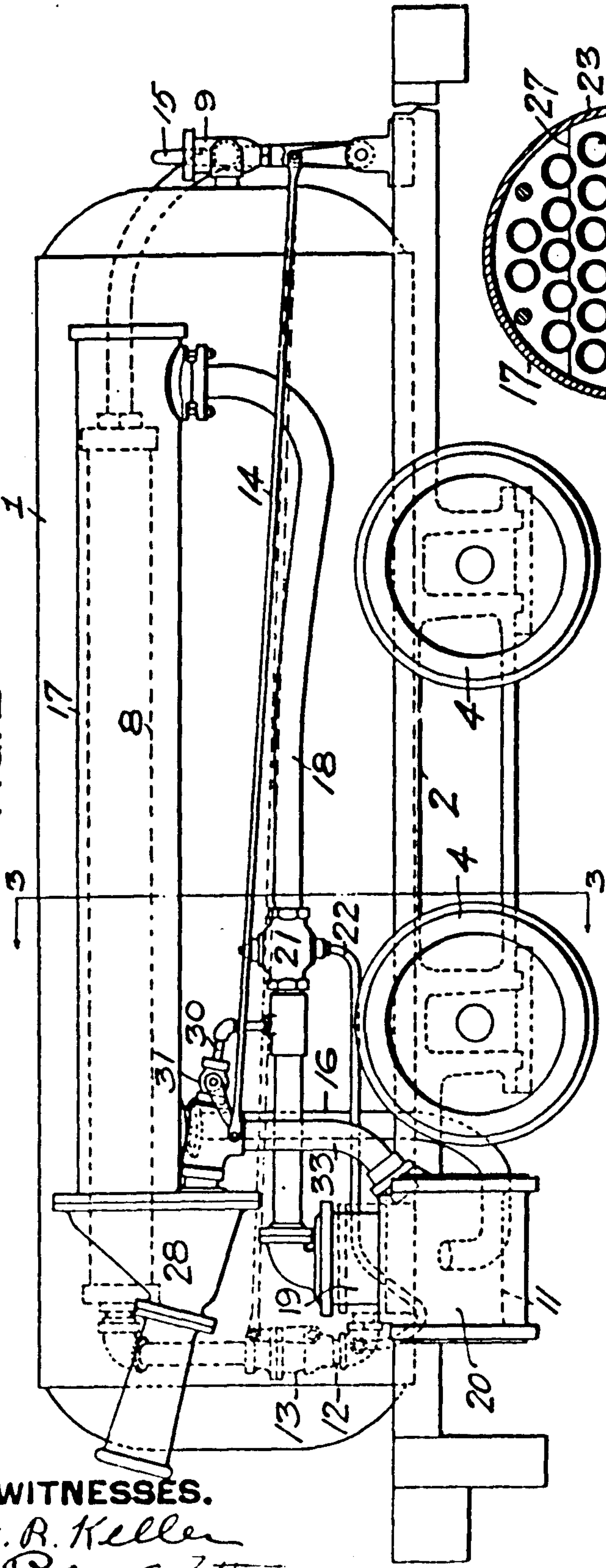


FIG. 2

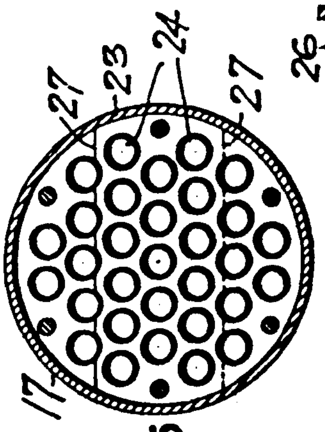


FIG. 5

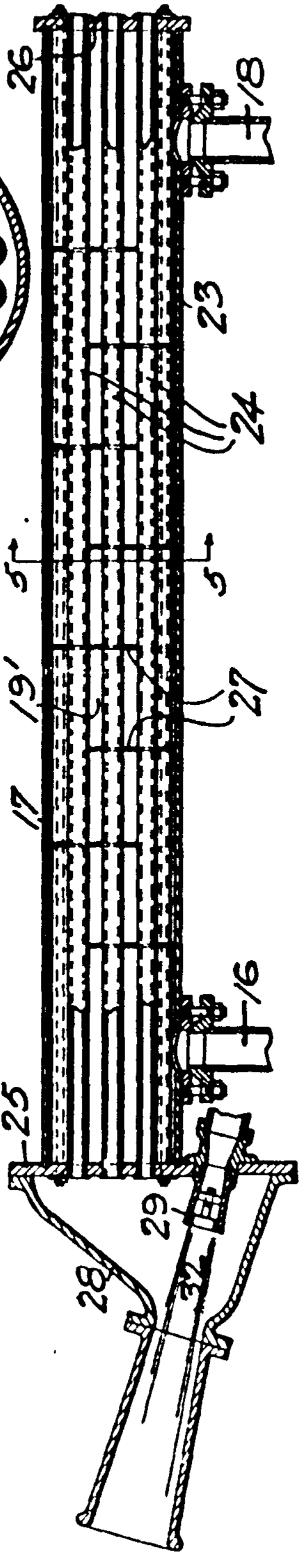


FIG. 4

WITNESSES.

J. R. Keller

Robert C. Totten

INVENTOR.

Charles B. Hodges

By Kay & Totten

attorneys

UNITED STATES PATENT OFFICE.

CHARLES B. HODGES, OF PITTSBURG, PENNSYLVANIA, ASSIGNOR TO H. K. PORTER COMPANY, OF PITTSBURG, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA.

COMPRESSED-AIR ENGINE.

953,336. Specification of Letters Patent. Patented Mar. 29, 1910.

Application filed June 11, 1909. Serial No. 501,643.

To all whom it may concern:

Be it known that I, CHARLES B. HODGES, a resident of Pittsburg, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Compressed-Air Engines; and I do hereby declare the following to be a full, clear, and exact description thereof.

My invention relates to compound compressed air engines, its object being to provide an engine of this type constructed to obtain the full and proper reheating of the air expanded within the high pressure cylinder and the proper operation of the engine, especially when applied to use for locomotives.

The invention comprises, generally stated, an engine having a main reservoir, an auxiliary reservoir, a long contracted air inter-heater and means for inducing a scouring draft through the inter-heater; as well as other improvements hereinafter described.

The special points of the invention desired to be covered will be set forth in the claims.

In the accompanying drawing Figure 1 is a side view of a locomotive engine embodying the invention; Fig. 2 is a side view partly broken away on the opposite side thereof; Fig. 3 is a cross section on the line 3—3 Fig. 2; Fig. 4 is an enlarged longitudinal section of the inter-heater; and Fig. 5 is a cross section thereof.

The apparatus best adapted for the practice of the invention as at present developed is illustrated in said drawings in connection with a locomotive engine, having the main air reservoir 1 supported on a suitable locomotive truck or underframe 2 mounted on the driving wheels 3 and 4 on two sides of the locomotive. On the high pressure side as illustrated in Fig. 1, the high pressure engine is shown at 5 while on the other side the low pressure engine is shown at 6, these engines being connected up to the wheels 3 and 4, said wheels being secured to the driving shafts or axles 7. The auxiliary reservoir 8 is supported on the main reservoir 1 and air is fed thereto from the main reservoir through a suitable reducing valve 9, bringing the air at proper pressure to the valve chest 10 of the high pressure cylinder 11. The pipe 12 leads to the high pressure cylinder and located therein is the controlling or throttle valve 13 which is connected by the rod 14 to the throttle lever 15. The pipe 16 leads from the exhaust passage of the high pressure cylinder 11 to the inter-heater 17, and the pipe 18 leads from the inter-heater to the valve chest 19 of the low pressure cylinder 20 from which cylinder the air is exhausted to the atmosphere. The inter-heater as illustrated in Figs. 2 to 5, is supported in a horizontal position on the side of the main reservoir and extends for practically the full length thereof, being made of small diameter and relatively great length, and is filled with a large number of small tubes to provide for a relatively strong or violent draft of air through the tubes thereof for reheating the compressed air. For example, in practical use I have found that with the cylinders 5 and 10 inches diameter by 10 inch stroke the best form of inter-heater is made of a casing 23 about 7 feet long and about 8 inches in inside diameter, this inter-heater being filled with a large number of tubes 24 extending for the full length of the inter-heater and seated in the end walls 25 and 26 thereof, the tubes being of small diameter, for example, about 30 tubes 1 inch in diameter being employed. I also prefer to employ within the inter-heater a suitable series of baffles 27 between the tubes 24 so as to cause the compressed air to be re-heated to travel in a circuitous course around said reheating tubes, these baffles extending alternately from the opposite sides of the inter-heater practically across the same and forming passages 19′ for the passage of the air within the heater in such circuitous course.

To induce a draft or current of atmospheric air through the inter-heater I may employ any suitable means, utilizing for example either air under pressure, or exhaust air from the low pressure cylinder, or both. Where air under pressure is employed for this purpose it may be drawn from any suitable part of the apparatus. I have illustrated it as drawn from the pipe 18 which leads from the interheater to the low pressure cylinder, and for that purpose I have employed the pipe 30 extending therefrom to the nozzle 28 at the exhaust end of the inter-heater, the pipe 30 leading to the air jet 29 entering said nozzle and thereby inducing a violent current through the tubes of the inter-heater. Where the supply of air is drawn from said pipe 18 I prefer to connect it to said pipe between the stop valve 21, and the valve chest of the low pressure cylinder, this stop valve being described in an application for patent filed by me October 26, 1908, Serial No. 459,642, and having a pipe 22 on the delivery side of the stop valve which communicates with the pipe 12 leading from the high pressure cylinder so that pressure from said pipe 12 will raise the valve when the main or throttle valve 13 is opened, and upon the closing of said main valve the pressure within the inter-heater and a spring will close the stop valve 21 and so hold the air within the inter-heater, cutting off the supply of air to the air jet 29, so that air under pressure is only supplied to said jet when the engine is in operation. By locating the valve 31 in the pipe 30 leading to the air jet the amount of air fed to the air jet can be controlled. To generate a stronger inducing current from the air under pressure the air jet as illustrated at 32 is of annular form, being shown as formed of a ring pipe with a series of jet orifices therein. To aid in inducing the draft through the inter-heater I may also employ the exhaust from the low pressure cylinder, and to that end the exhaust pipe 33 may connect with the pipe 30, as illustrated in Fig. 2, so enabling me to utilize both the exhaust air and air under pressure for generating a strong scouring current through the inter-heater.

In the use of the invention the compressed air is stored at a relatively high pressure, usually about 800 pounds, within the main reservoir 1, and it is maintained within the auxiliary reservoir 8 at the desired pressure for the operation of the engine, say, at about 250 pounds. Upon the operation of the throttle valve 13 the air passes to the cylinder 11 of the high pressure engine and moves the piston therein, escaping therefrom at a relatively low pressure, for example, in the best practice at about 50 pounds. The sudden and rapid expansion of the air while moving the piston within the high pressure cylinder causes a violent drop in the temperature of the air. For example, if it enters at an average atmospheric temperature of 60° Fahrenheit, the air passes therefrom at a temperature below lowest atmospheric temperature, the reduction of temperature being usually about 140° F., so that it is brought to a temperature of about 80° F. below zero. At such low temperature the volume of air is insufficient to fill the low pressure cylinder at a pressure of 50 pounds where the cylinders are made of what I have found to be the most desirable relative sizes, for example, where the cubical contents of the low pressure cylinder is about four times that of the high pressure cylinder, and to obtain the best results and give a substantial balance of the power generated by the two engines the air should be increased to about four times the volume at which it enters the high pressure cylinder. The difference in temperature between the exhaust air when it enters the inter-heater and atmospheric temperature is so great that it quickly causes condensation of moisture carried in the atmosphere which forms a coating of frost over the exposed surfaces of the inter-heater such as within the tubes 21 thereof, and this frost coating serves as a non-conductor, and when a short vertical inter-heater of the construction illustrated in Letters Patent No. 868,560, granted to me October 15, 1907, is employed the frost coating under certain conditions forms on the exposed surfaces of such tubes and prevents the full reheating action of the atmospheric air passing through the same and gradually gathers so that unless removed it will clog and partially close the tubes so reducing the current of air carried therethrough and impair the operation of the inter-heater. By the employment of the inter-heater as illustrated in this application, however, where a long contracted horizontal inter-heater of small diameter having a large number of small tubes is employed, I am enabled to induce a very violent draft through the tubes of the inter-heater by the suction action obtained, such as by the discharge of air under pressure or by exhaust air from the low pressure cylinder, or both, and such violent draft of atmospheric air through the tubes acts to scour over the surfaces thereof, on account of the large amount of air carried through the small tubes and thereby prevents the formation of frost on the exposed surfaces of such tubes and scours off any such frost in case it is formed thereon, so keeping the tubes of the inter-heater clear from frost and enabling the air carried therethrough to impart its full reheating action to the compressed air confined within the inter-heater. I have found that by the employment of such construction and the violent scouring draft through the tubes resulting therefrom I am able to keep such tubes clear from frost even when operating the engine at atmospheric temperatures considerably below freezing point, and thus to obtain the efficient operation of the engine under such extreme conditions. The amount of air under pressure used to obtain such scouring action can be controlled by the valve 31 within the air jet pipe 30 according to atmospheric conditions, while by taking the air under pressure for operating the jet from the pipe 16 between the stop valve 21 and the low pressure cylinder, the discharge of the air through the air jet is controlled by the operation of the main throttle valve and no air for such purpose is wasted when the engine is not in operation, but is automatically fed to the air jet as soon as the throttle valve is opened and the stop valve is also opened to admit air from the inter-heater to the low pressure engine.

In application of even date herewith, Serial No. 501,611, I have described and claimed the general method of operating a compound compressed air engine consisting in carrying the compressed air through and expanding it in one cylinder and reheating the exhaust air by extended exposure thereof to air heating at atmospheric temperature, carrying the reheated air through a low pressure cylinder; and in application of even date herewith, Serial No. 501,612, I have described and claimed the special method practiced by the apparatus here set forth in which such a violent current of air is carried over the exposed surfaces of the inter-heater as to scour from or prevent the formation of frost on such surfaces.

Application filed by me of even date herewith Serial No. 501,639, describes and claims the employment of the same lever for operating the main throttle valve and means for inducing a current over the exposed surfaces of the inter-heater.

What I claim is:

1. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, said inter-heater having a long contracted body of small diameter filled with a large number of tubes of small diameter, and means for inducing a current of atmospheric air through said tubes sufficient to cause a scouring draft through the said tubes and prevent the formation of frost thereon.

2. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, an inter-heater between them having large exposed surfaces and having a nozzle on the discharge end thereof, an air jet communicating with said nozzle and a pipe carrying air under pressure as high as that entering the low pressure cylinder and communicating with said air jet.

3. In a compound compressed air engine, the combination of a high pressure cylinder, a low pressure cylinder, an air inter-heater, a pipe leading from the exhaust of the high pressure engine to said inter-heater, and a pipe leading from said inter-heater to the low pressure cylinder, and a pipe leading from said latter pipe to supply air under pressure to produce the current of air over the exposed surfaces of the inter-heater.

4. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, an inter-heater, a pipe leading from the high pressure engine to the inter-heater and a pipe leading from the inter-heater to the low pressure engine, said pipe having a stop valve located therein, and a pipe connected to said pipe between the stop valve and the low pressure engine for supplying air under pressure to produce a draft over the exposed surfaces of the inter-heater.

5. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, an inter-heater between them having a discharge nozzle and an air jet to induce a draft over the exposed surfaces of the inter-heater, a pipe carrying air under pressure as high as that entering the low pressure cylinder and leading to said air jet and a pipe leading from the exhaust of the low pressure engine to said air jet.

In testimony whereof, I the said CHARLES B. HODGES have hereunto set my hand.

CHARLES B. HODGES.

Witnesses:
ROBERT C. TOTTEN,
J. F. WILL.

C. B. HODGES.

COMPOUND COMPRESSED AIR ENGINE.

APPLICATION FILED JUNE 11, 1909.

979,165.

Patented Dec. 20, 1910.

2 SHEETS—SHEET 1.

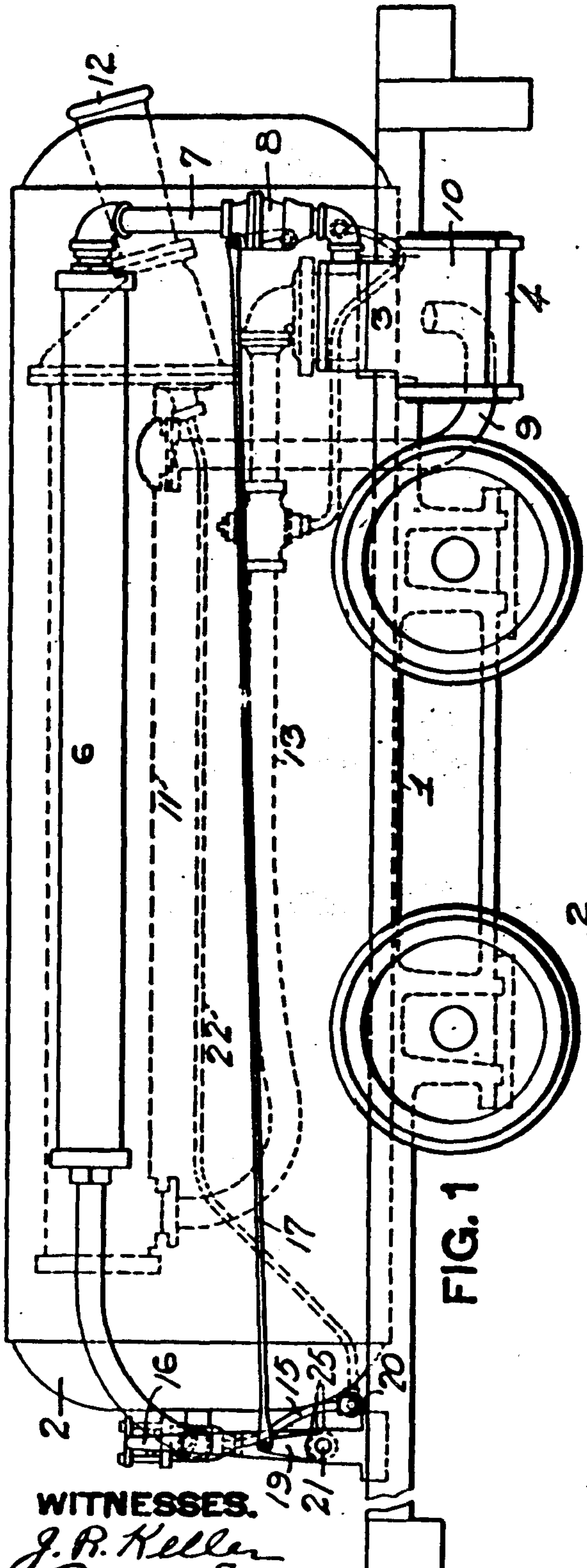


FIG. 1

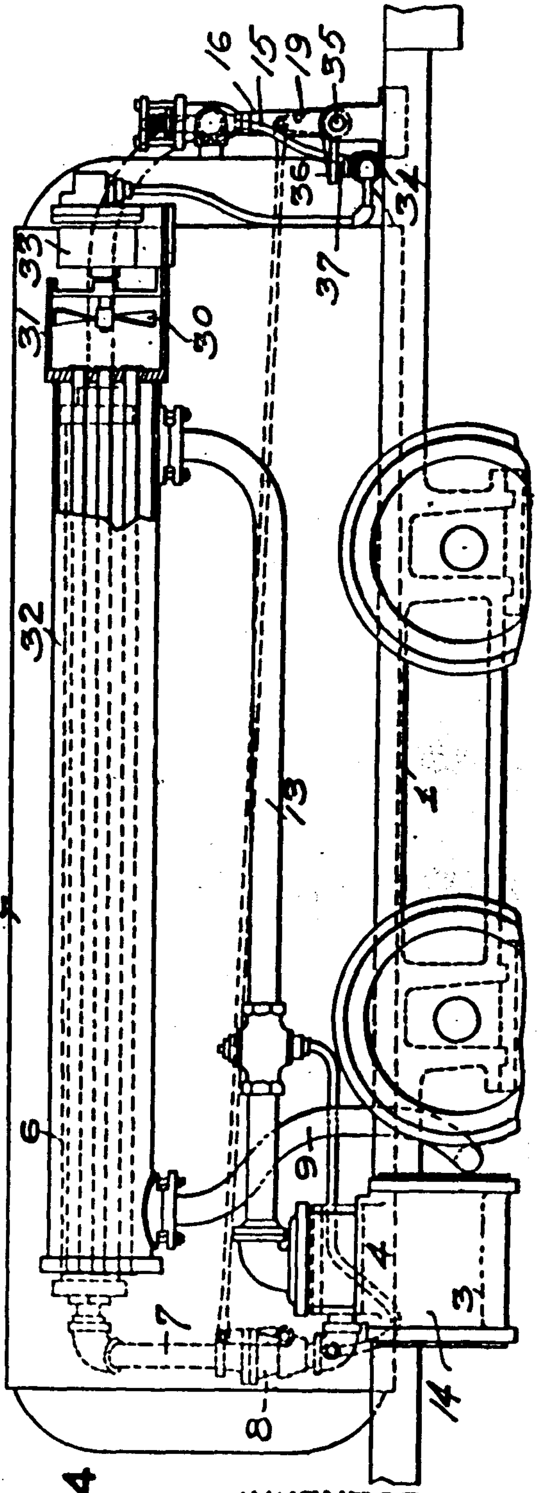


FIG. 4

WITNESSES.

J. R. Keller

Robert C. Totten

INVENTOR.

Charles B. Hodges

By Kay & Totten

attorneys

C. B. HODGES.

COMPOUND COMPRESSED AIR ENGINE.

APPLICATION FILED JUNE 11, 1909.

979,165.

Patented Dec. 20, 1910.

2 SHEETS—SHEET 2.

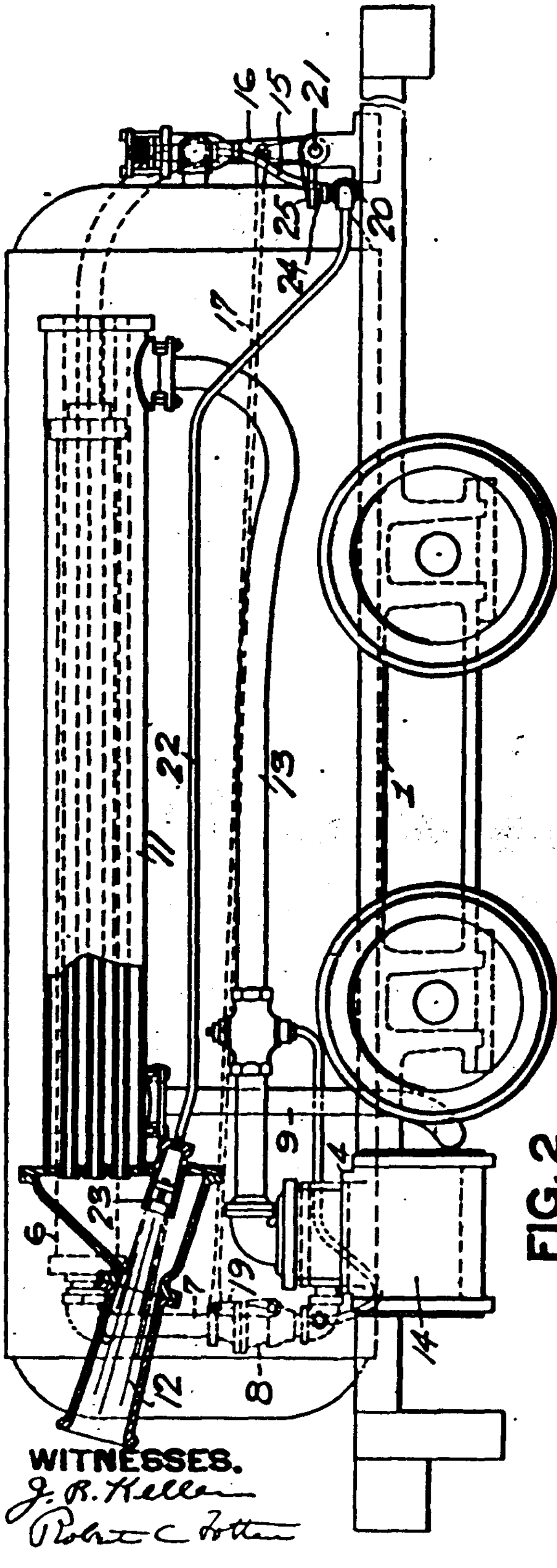


FIG. 2

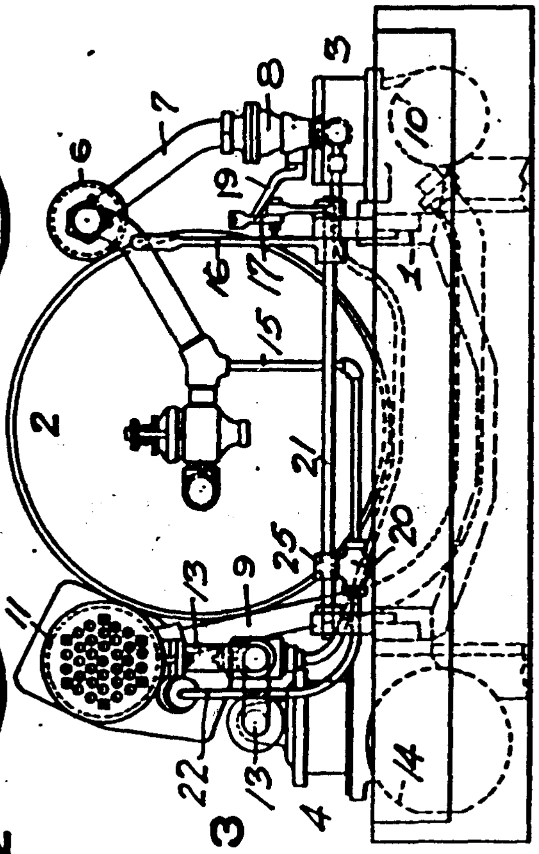


FIG. 3

WITNESSES.

J. R. Keller

Robert C. Totten

INVENTOR.

Charles B. Hodges

By Kay & Totten

Attorneys

UNITED STATES PATENT OFFICE.

CHARLES B. HODGES, OF PITTSBURG, PENNSYLVANIA, ASSIGNOR TO H. K. PORTER COMPANY, OF PITTSBURG, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA.

COMPOUND COMPRESSED-AIR ENGINE.

979,165. Specification of Letters Patent. **Patented Dec. 20, 1910.**

Application filed June 11, 1909. Serial No. 501,639.

To all whom it may concern:

Be it known that I, Charles B. Hodges, a resident of Pittsburg, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Compound Compressed-Air Engines, (Case 1;) and I do hereby declare the following to be a full, clear, and exact description thereof.

My invention relates to compound compressed air engines, its object being to provide means for carrying the air used for reheating the compressed air over the exposed surfaces of the inter-heater between the high pressure engine and the low pressure engine and to control the same in connection with the operation of the engines through its main or throttle valve.

It comprises, generally stated, in combination with a high pressure engine, a low pressure engine and the interheater between the same, of the throttle valve controlling the supply of air to the engine, means to induce a current of atmospheric air over the surfaces of the inter-heater, a valve controlling the supply of air under pressure to induce such current, and lever mechanism controlling both the throttle valve and said current inducing valve as hereinafter described.

In the accompanying drawings Figure 1 is a side view of one side of a locomotive engine embodying the invention; Fig. 2 is a side view partly broken away of the other side of such engine; Fig. 3 is an end view illustrating the valve mechanism for controlling the throttle and air jet valves; and Fig. 4 is a view of a modification.

The invention as illustrated in the drawings is applied to a locomotive engine and will be described in connection with the same. The engine has the engine truck 1, the main air reservoir tank 2, the high pressure engine 3, and low pressure engine 4, said engines being connected up with the driving wheels of the locomotive. The engine is also provided with the auxiliary reservoir 6 from which air passes through the pipe 7 to the valve box of the high pressure engine, the main or throttle valve 8 being located in this pipe. The exhaust pipe 9 leads from cylinder 10 of the high pressure engine to the interheater 11 which, as shown, is supported on the main tank 2 and extends longitudinally thereof and is provided with a series of pipes extending through the same to provide an extended heating surface for the air from the high pressure cylinder, the inter-heater having also the nozzle 12 by which a strong air draft or current of air at atmospheric pressure is induced through the pipes of the inter-heater. The pipe 13 leads from the inter-heater to the valve box of the low pressure cylinder 14.

Air under pressure is supplied to the inducing nozzle 12 to cause a draft or current through the pipes of the inter-heater, such air being drawn from any suitable part of the apparatus containing air under pressure. I have illustrated this having a pipe 15 which extends from the supply pipe to the auxiliary reservoir 6 into the engineer's cab close to the throttle valve lever 16 which, as shown in Fig. 1, has the rod 17 extending to the throttle valve 8 and operating the same through the lever 19. The said pipe 15 has the air jet controlling valve 20 located close to the shaft 21 of the throttle lever 16, and the pipe 22 extending therefrom to the nozzle 12 of the inter-heater and communicating with the air jet 23 discharging into said nozzle so as to induce a draft through the inter-heater and so draw the atmospheric air over the exposed surfaces thereof, such as through the series of pipes within the inter-heater.

As shown in Fig. 3, the air jet controlling valve 20 has its valve stem 24 extending up through the valve body close to the throttle lever shaft 20, and said throttle lever shaft has the auxiliary arm 25 extending over the valve stem of said air jet valve in position to control the same, that is, to force the same to its seat when the throttle valve is closed, but to open the same when the throttle valve is opened so as to permit passage of the air under pressure through the pipe 22 to the inducing nozzle 12 of the interheater and induce the current of air through the inter-heater and so cause the reheating of the air after its passage from the high pressure cylinder to the low pressure cylinder.

In the operation of the engine the compressed air from the auxiliary reservoir 6 upon the opening up of the throttle valve passes through the high pressure cylinder and is expanded therein and in this way its temperature is lowered much below atmospheric temperature and in order to increase its volume by reheating it is carried through the interheater and while confined therein is exposed to a large amount of atmospheric air, the air for example passing through the tubes of the interheater and on account of the difference in temperature of the refrigerated and expanded air the air at atmospheric temperature acts to reheat the same and bring it back to proper volume, after which it passes through the low pressure cylinder and is expanded therein and discharged.

The throttle lever shaft is so arranged as to open the air jet valve in proportion to the opening of the throttle valve, and it thus gives full control through the operation of the one lever to the necessary operative parts of the compressed air engine; and as only a small amount of air is required to induce the necessary air current through the interheater when the engine is running at slow speed, and for that purpose the main throttle valve is open for a relatively small distance and the air requiring reheating in the interheater is relatively small, it is evident that but a small amount of air is required to induce the current through the inter-heater. Full control is therefore given of the supply of the air to the air jet through the operation of the ordinary throttle valve lever, and when more power is needed and a greater amount of air required to operate the engines, in like manner the supply of air to the air jet is also increased while the closing of the throttle valve cuts off the entire supply to the air jet pipe, so that there is little or no waste of air for such purpose.

Fig. 4 illustrates a modification of the invention in which the draft through the interheater is induced by means of a fan. In such case the fan 30 is located within the tubular extension 31 of the inter-heater 32 and it is illustrated as driven by means of an air motor or air turbine which is shown diagrammatically at 33. In order to operate the said fan and so induce the current through the inter-heater I employ a like valve 34 of the same character as the air jet controlling valve 20 above described which controls the supply of air to the air motor 33 and this valve is operated in the same manner as above described in connection with the said air jet controlling valve 20, being located close to the main throttle lever shaft 35 which has the auxiliary arm 36 extending over the valve stem 37 of the valve so that by the movement of the main throttle lever the valve controlling the air to operate the fan is controlled in like manner and the speed of the air motor operating the fan is regulated according to the position of the throttle lever.

The general method of operating compressed air engines in which the air at high pressure is carried through one cylinder and thereby reduced below highest atmospheric temperature and the exhaust air pressure is reheated when confined by extended exposure to atmospheric temperature and then carried through a low pressure cylinder, and the specific methods in which exhaust air from the low pressure cylinder while still under pressure is discharged to induce a draft over the exposed surface of the interheating receptacle, are set forth and claimed in Letters Patent No. 953,334, granted to me March 29, 1910, upon application filed of even date with this application. The method of operating such compound compressed air engines, consisting in carrying the compressed air at high pressure through and expanding it within one cylinder and thereby reducing it below atmospheric temperature, confining such exhaust air from said cylinder within a receptacle and inducing over the exposed surface of such receptacle a violent current of air at atmospheric temperature sufficient to scour from or prevent the formation of frost on the exposed surfaces of said receptacle and thereby reheating and increasing the volume of such exhaust air and its capacity to generate power, carrying the reheated air through a low pressure cylinder, is included in Letters Patent No. 953,335, dated March 29, 1910, upon application filed of even date with this application.

In an application filed by me of even date herewith, Serial No. 501,610, is claimed the specific apparatus for producing a draft over the exposed surfaces of the interheater by means of a fan in a tubular extension in the end of the interheater and an independent air motor driving said fan.

What I claim is:

1. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine and an inter-heater between them, a main throttle valve, means for inducing a current over the exposed surfaces of the inter-heater, a valve controlling the same and a lever controlling both the main throttle valve and the current inducing valve.

2. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, a main throttle valve, an air jet nozzle for inducing a current over the exposed surfaces of the inter-heater, an air jet valve feeding air under pressure to said nozzle, and a lever controlling both the throttle valve and the air jet valve.

3. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, a throttle valve and a throttle lever controlling the same, means operated by air under pressure for inducing a current over the exposed surfaces of the interheater, and a valve controlling the current inducing means located close to the throttle lever and operated thereby.

4. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, means operated by air under pressure for inducing a current over the exposed surfaces of the inter-heater, and a valve controlling said inducing means, a throttle valve, and a throttle lever connected to the throttle valve and having an auxiliary arm controlling the current inducing valve.

In testimony whereof, I the said CHARLES B. HODGES have hereunto set my hand.

CHARLES B. HODGES.

Witnesses:
ROBERT C. TOTTEN,
J. F. WILL.

C. B. HODGES.

COMPRESSED AIR ENGINE.

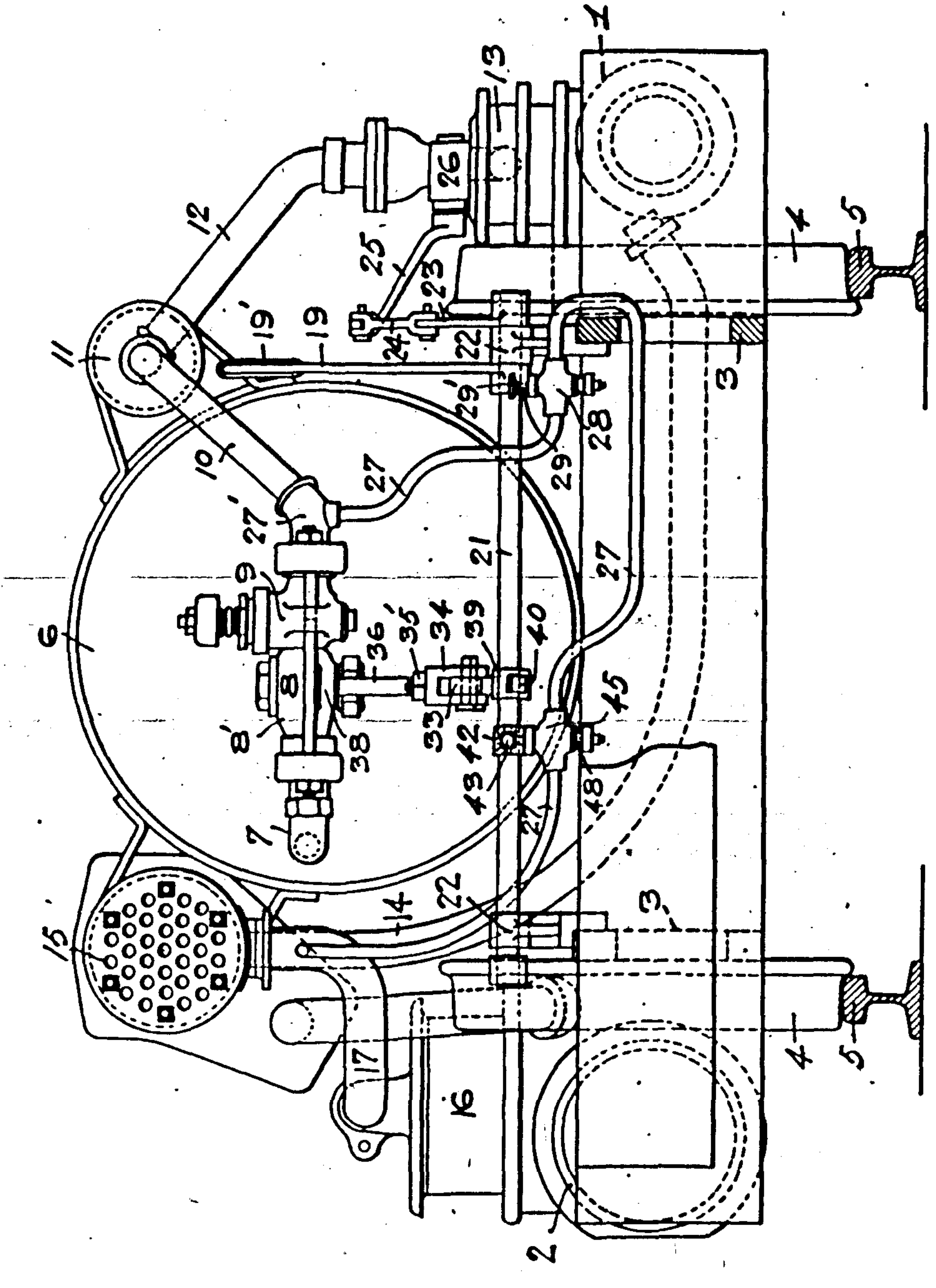
APPLICATION FILED JULY 31, 1911.

1,024,778.

Patented Apr. 30, 1912.

3 SHEETS—SHEET 1.

FIG. 1



WITNESSES.

J. R. Keller

Robert C. Totten

INVENTOR.

Charles B. Hodges

By Kay & Totten

Attorneys

C. B. HODGES.

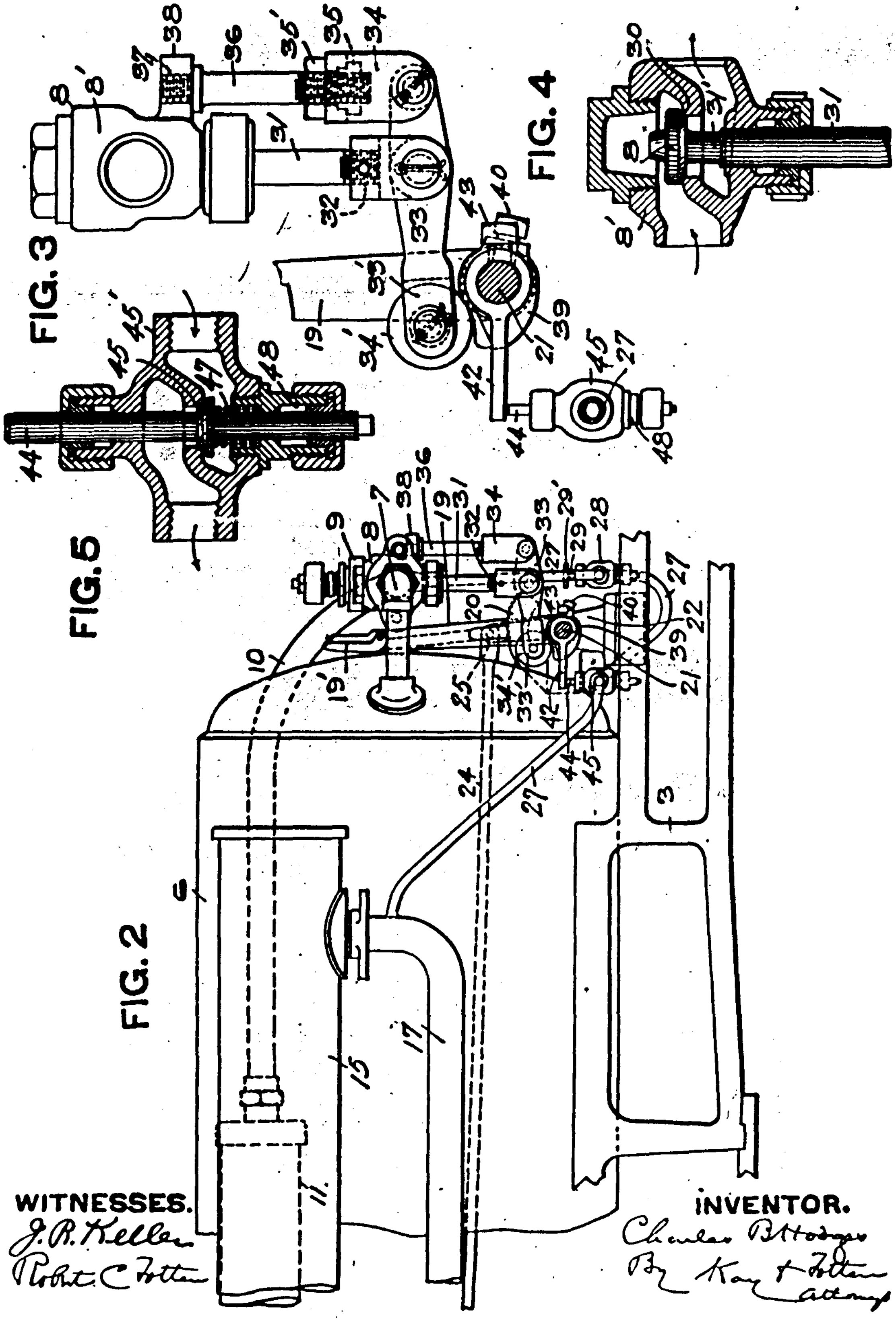
COMPRESSED AIR ENGINE.

APPLICATION FILED JULY 21, 1911.

1,024,778.

Patented Apr. 30, 1912.

2 SHEETS—SHEET 2.



WITNESSES.

J. R. Keller

Robert C. Totten

INVENTOR.

Charles B Hodges

By Kay & Totten attorneys

UNITED STATES PATENT OFFICE.

CHARLES B. HODGES, OF PITTSBURGH, PENNSYLVANIA, ASSIGNOR TO H. K. PORTER CO., OF PITTSBURGH, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA.

COMPRESSED-AIR ENGINE.

1,024,778. Specification of Letters Patent. Patented Apr. 30, 1912.

Application filed July 31, 1911. Serial No. 641.506.

To all whom it may concern:

Be it known that I, CHARLES B. HODGES, a citizen of the United States, and resident of Pittsburgh, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Compressed-Air Engines; and I do hereby declare the following to be a full, clear, and exact description thereof.

My invention relates to compressed air engines, and more particularly to those of the type applied to the running of locomotives. Its object is to improve in certain particulars on a previously known type of compressed air engines, so as to render it more nearly fool proof and with a more simple and durable construction than has hitherto been employed.

In this type of engine a reducing valve is usually employed to reduce the pressure of the air from the main reservoir, so that it enters the initial cylinder at a substantially uniform reduced pressure. However, when the operation of the engine is stopped, the reducing valve, owing to the necessary nature of its construction, does not entirely interrupt the passage of air, so that the pressure of air would pile up in the connection to the cylinder, or in the secondary reservoir interposed ahead of the same unless some means is employed to cut it off. The means employed, as described below, is preferably a stop valve interpesed in the connection between the main reservoir and the reducing valve and which may be closed when the throttle valve is closed. As, however, it is desirable where more than one cylinder is employed to admit air in starting to the low pressure or secondary cylinder, I provide a by-pass around the high pressure cylinder, to the interheater or directly to the low-pressure cylinder. This by-pass is necessarily controlled by a valve. If, however, the use of this valve is abused so that it is opened during the normal operation of the engine or locomotive, the parts are subjected to great strain owing to the excess pressure in the low pressure cylinder, and serious injury results.

The particular object of my present invention therefore is to provide an improved construction of mechanism by which the by-pass above described is automatically closed when the throttle valve is open to admit air to the primary or high pressure cylinder.

The said invention contemplates, generally stated, the combination with a high and a low pressure cylinder, an air reservoir and a connection between the same and the high pressure cylinder provided with a throttle valve and a valve or valves controlling said connection ahead of the same, such as the stop valve below described, of a by-pass communicating with said connection beyond such valve and ahead of the throttle valve and leading to the low pressure cylinder, a valve controlling said by-pass, and preferably also a manually operated valve also controlling the by-pass, and mechanism such as a throttle lever controlling the throttle valve and arranged to directly open the by-pass controlling valve when the throttle valve is closed. The said mechanism consists preferably, with a normally closed valve in the by-pass, in a finger or cam carried by a shaft actuated by the throttle lever, the reservoir connection controlling valve stem being preferably operated by a cam carried by the same shaft.

In the accompanying drawings, Figure 1 is an end elevation of a locomotive engine illustrating my invention. Fig. 2 is a partial side view of the same. Fig. 3 is a detail side view partly in vertical section on a larger scale illustrating the operation of the by-pass controlling valve and the mechanism actuating the same directly. Fig. 4 is a detail vertical section through the stop valve; and Fig. 5 is a like section through the by-pass controlling valve.

In the said drawings the primary or high pressure engine cylinder 1 and secondary or low pressure engine cylinder 2 are each mounted in the frame 3 of the locomotive shown, which is provided with suitable wheels 4 carried on the rails 5. The main air reservoir 6 is also mounted on the frame 3 in a suitable manner and is provided with an elbow 7 which leads into the stop valve 8 and through the same and the reducing valve 9 to the connecting pipe 10 leading to the secondary or auxiliary reservoir 11. The connecting pipe 12 leads from the said reservoir 11 to the valve chest 13 of the cylinder 1. The exhaust pipe 14 leads from the exhaust of the high pressure cylinder 1 to the interheater 15; and the pipe 17 connects the interheater with the valve chest 16 of the low pressure cylinder 2.

The throttle lever 19, which is preferably provided with the latch handle 19′ and segment rack 20, is mounted on a shaft 21 journaled in the bearings 22 attached to the frame 3. The arm 23 is attached to the same shaft 21 and is pivotally connected to the rod 24 extending longitudinally of the reservoir 6 and pivoted to the valve stem arm 25, which controls the throttle valve 26. It will be noticed that the throttle valve 26 is interposed in the pipe 12 just ahead of the valve chest 13. The by-pass 27 is tapped off from the pipe connection 10, 12 between the said throttle valve 26 and the reducing valve 9, being illustrated as joined to an elbow 27′ near the reducing valve. The said by-pass 27 leads to the low pressure cylinder 2, being shown as entering the pipe 16 connecting the same with the interheater 15. The by-pass pipe 27 is provided with the spring pressure valve 28 having a stem 29 and treadle portion 29′ by which said valve is opened by the port, it being so constructed as to remain normally closed in a manner well understood in the art.

The stop valve 8 is provided with a casing 8′ and a seat 30 for the valve head proper 8, being illustrated as downwardly closing. It has the downwardly extending stem 31 which is provided at its lower end with a screw head 32 to which is pivoted the valve lever 33. The valve stem 31 has preferably a reduced portion 31′ within the casing 8′. The effective area of the upper pressure face of the valve 8, above the valve seat 30, is therefore much greater than the effective area of its opposite pressure face, the difference being substantially equivalent to the horizontal cross-section of the portion 31′ of the valve stem 31, when the valve is open. There is therefore, during normal operation, a force tending to close this valve equal to the pressure per square inch in the reservoir 6 times the cross-sectional area of the valve stem portion 31′. When the valve is closed, however, owing to the decrease of pressure per square inch beyond the valve 8, the difference in total pressures on the opposite faces of the valve 8, is greatly increased; so that a very great force is necessary to raise the valve 8 from its seat 30. The said valve stem 31 is controlled through the lever 33 which is fulcrumed to the adjustable bracket head 34 secured by the sleeve-nut 35 and lock-nut 35′ to the bracket rod 36 illustrated as attached by the thread 37 to the lug 38 on the valve casing 8′. The said lever 33 is preferably provided near the end of its arm 33′ with the antifriction roller 34 against which the cam 39 plays. The said cam 39 is fixed to the shaft 21, as by the screw bolt 40, and is arranged to raise the lever 33 at a progressively increasing rate so as to gradually open the valve 8, as pointed out more fully in another application of even date herewith, Serial No. 611,526, filed by Daniel R. Murphy. The said cam and lever mechanism for operating the stop valve 8 form thus no part of my present invention, although I have embodied the same in my improved combination to be more specifically described and claimed. Also carried on the rod or shaft 21 is the trigger or finger 42, which is fastened to the said shaft in any desired manner as by the screw bolt 43, and is arranged to engage the stem 44 of the valve 45, the casing 45′ of which is threaded into the by-pass connection 27. The said stem 44 and valve head proper 45 are normally held in closed position by the spring 47, the stem 44 extending downwardly preferably through the stuffing box 48 so that the parts are conveniently accessible for adjustment or repair.

The position of the finger 42 on the shaft 21 is so adjusted that when the throttle lever is moved to open the throttle valve 26, the said finger 42 is rotatably raised by the shaft 21 so that the valve 45 is automatically closed by the spring 47 and the action of the compressed air. The by-pass 27 is therefore automatically closed at all times when the throttle valve 26 is open, so that the operator or engineer cannot impair the working of the machine by admitting air from the pipe connection 10 through the by-pass to the low pressure cylinder 2 during its normal operation. It is apparent, however, assuming the machine to be at rest and the throttle valve 26 closed, in which case the stop valve 8 is also closed, that the engineer by opening the valve 29 can admit air from the pipe 10 and auxiliary reservoir 11 to the low pressure cylinder 2. The throttle valve being then opened, an extra pressure of air is obtained in the two cylinders to start the engine. As the valve stem 44 of the valve 45 is covered by the finger 42, it is impossible or at least highly inconvenient to depress the same and open the by-pass 27 subsequently. Consequently during normal running the machine must be operated in its normal fashion, all the air passing in succession through the two cylinders.

What I claim is:

1. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve controlling said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said low-pressure cylinder, a valve controlling said by-pass, a throttle lever, and mechanism directly movable thereby to simultaneously open said throttle valve and close said controlling valve.

2. In compressed air engines, the combi-

nation with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a normally operative valve controlling said by-pass, and mechanical means controlling said throttle valve and arranged to directly open said last mentioned valve when the throttle valve is closed, and to insure its closing when the throttle valve is open, substantially as described.

3. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a manually operative valve in said by-pass, another valve controlling said by-pass, a throttle lever connected to said throttle valve, and mechanical means closing said first aforementioned valve in said reservoir connection, and opening said last mentioned valve controlling said by-pass when said controlling lever is moved to close said throttle valve, and opening said by-pass connection when said throttle lever is oppositely moved.

4. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a throttle lever controlling said throttle valve, a shaft actuated by said lever and provided with a finger, and a valve controlling said by-pass and opened by said finger when the throttle valve is closed.

5. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a rotary shaft, a throttle lever carried thereby and controlling said throttle valve, means carried thereby operating said first aforementioned valve, two valves arranged in said by-pass, the first of which is manually operative, and a finger carried by said shaft arranged to open the second of which valves when the throttle valve is closed, and to permit its closing when the throttle valve is open.

6. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said low pressure cylinder, a valve controlling said by-pass, a rotary shaft, a lever actuating the same, and controlling said throttle valve, and means carried by said shaft connected to said last mentioned valve and to said first mentioned valve in said reservoir connection for controlling the same, substantially as described.

7. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve controlling said connection, and another valve controlling said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between aforesaid valves to said low pressure cylinder, a manually operative valve normally closing said by-pass, another valve controlling said by-pass and provided with a spring normally closing the same, a rotatable shaft, a throttle lever actuating the same, means carried by said shaft for closing aforesaid second mentioned valve controlling said reservoir connection, and a finger carried by said shaft adapted to open said second-mentioned valve controlling said by-pass.

In testimony whereof, I, the said CHARLES B. HODGES have hereunto set my hand.

CHARLES B. HODGES.

Witnesses:
ROBERT C. TOTTEN,
J. R. KELLER.

Copies of this patent may be obtained for five cents each, by addressing the "Commissioner of Patents, Washington, D. C."

Department of Energy

DOE/CS-0088

May 1979

Heat Pumps

How Efficient Is a Heat Pump?

The efficiency of a home heating system is measured by the number of units of heat energy output obtained for each unit of energy input. **Of all the conventional heating systems available today, heat pumps alone can return more heat than they consume.**

How can heat pumps multiply their energy input? In simplest terms, while conventional systems use energy to ***create*** heat, heat pumps use energy to ***transfer*** and ***intensify*** heat that is already available in the surrounding environment. A heat pump uses energy only to run the fan and the compressor.

Heat pumps are not new; electric heat pumps were originally developed and marketed in the 1930s.

Even very cold air contains heat—"cold" simply means that some, but not all, of the heat has been removed. For example, at 0°F, air contains 89 percent of the heat available at 100°F. Heat is totally absent from the air only at a temperature of absolute zero, or 460° below 0°F. Thus, even on a cold day, a heat pump can extract some heat from the outdoor air and pump it into a building to maintain a comfortable temperature.

BASIC REFRIGERATION Guy R. King, 1951

However, this is of less interest than the relationship between the refrigeration produced and the power required. In this case this would be

$$\frac{50.8}{11.2} = 4.52$$

Since this is more than 1.00 or 100 percent it cannot be considered an efficiency. It is called the Coefficient of Performance. In this case there is 4.52 times as much refrigeration produced as power consumed. This is not a form of perpetual motion, since the heat is merely transfered from the evaporator to the condensing water. The compressor is acting in the form of a heat pump to move the heat to the condenser.

The heat pump appears to do the impossible

Sunset

November 1977

As a home heater, the heat pump seems to achieve the impossible: It moves heat uphill, in a thermal sense, from the cold outdoors to the warmer indoors—in the process, *seeming to produce more energy than it consumes.* The heat pump is assuming major importance as we rely more on electricity for heating, and its use is mushrooming in the West.

How the "impossible" works

The key to heat pump economics: The device is just picking up and moving already existing sun-generated heat energy present in even very cold winter air. This can be much less expensive than *creating* heat with electricity. Under ideal conditions, the coefficient of performance—the ratio of heat output to energy use by the heat pump—can be as high as three to one.

Other Homes and Garbage
Leckie, Masters, Young,
Whitehouse, 1975
Sierra Club Books

As we have seen, the net effect of the heat pump is that energy is removed from a cooler region and "pumped" to a warmer one. Energy does not flow spontaneously from lower to higher temperatures, which is the reason for the compressor. The key question, of course, is how much energy is required to run the compressor? This depends on the operating temperatures involved, but usually we require one unit of compressor energy for every three or four units of energy delivered to the living space. This implies that we receive two or three units of energy "free" from the outside air! Sounds like magic, doesn't it?

Magic or not, these systems do work. Not only do they work, but the cycle can be reversed in the summer to cool the building! Your local General Electric or Westinghouse dealer can provide you with literature on heat pumps which have been available commercially for nearly two decades. A typical unit is shown in Figure 4.54a.

Heat pumps can be combined with a simple solar collection system for some striking results (see Figure 4.54b). The synergistic effects can be explained in terms of the heat pump's coefficient of performance (*COP* for short). The *COP* is defined in the following way:

$$\textbf{E. 4.36}\quad COP = \frac{\textit{Heat to Living Space}}{\textit{Energy Input to Compressor}}$$

In other words, the *COP* is the ratio of what you get out to what you put in.

Operating Experience With An Experimental Heat Pump System

Energybook 2
ed. John Prenis

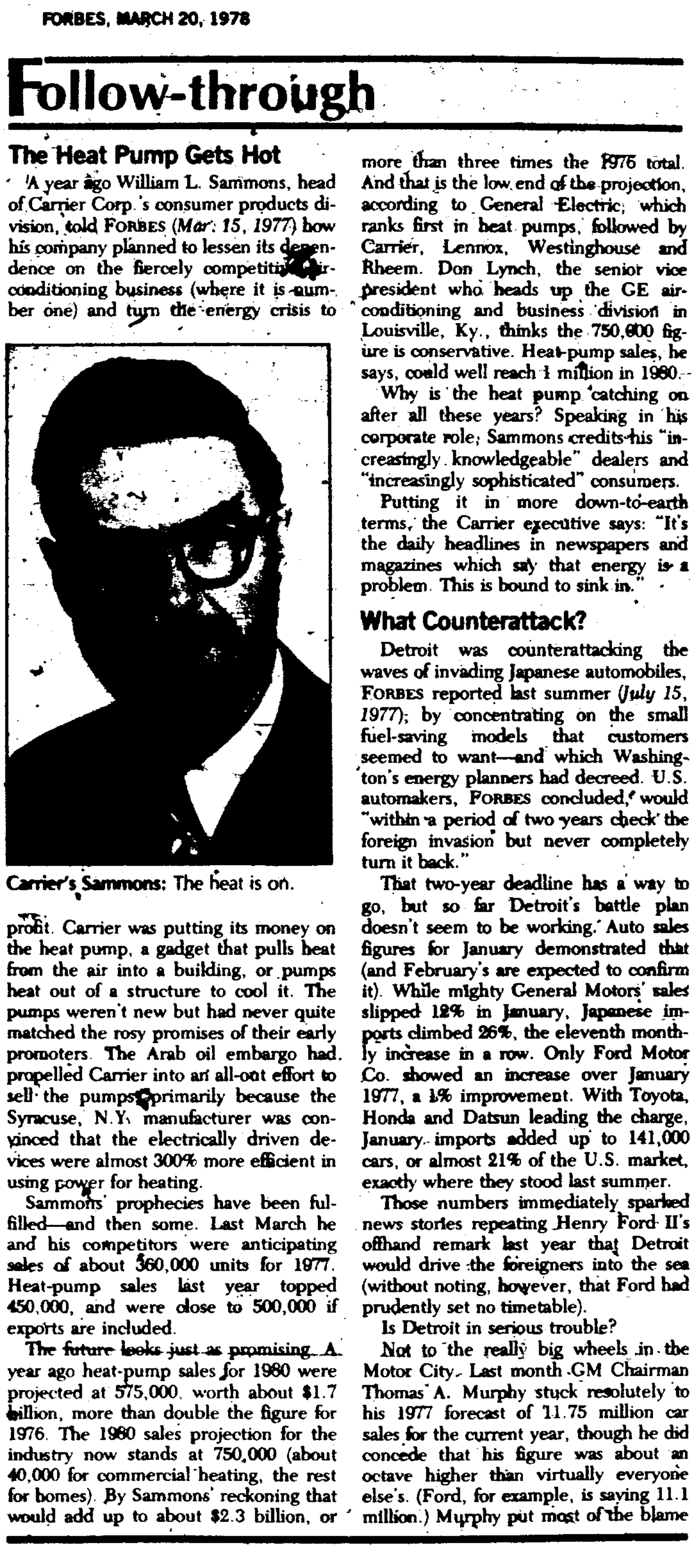
Richard La Rosa

The heat pump is theoretically capable of a C.O.P. given by the formula

$$\text{C.O.P.} = \frac{T_2}{T_2 - T_1}$$

where T_2 is the absolute temperature of the refrigerant in the condenser, and T_1 is the absolute temperature of the refrigerant in the evaporator. (Add 460 to the Fahrenheit temperature to get absolute temperature.) For room heating from 50°F water, T_2 might be 90 + 460 and T_1 might be 30 + 460. The C.O.P. would be 550/60 = 9.2. We allowed for a 20 degree differential between the water and the refrigerant in the evaporator heat exchanger, and a 20 degree differential between the refrigerant and the room air in the condenser heat exchanger.

To achieve the C.O.P. of 9.2 we would have to devise a machine that would push a suitable refrigerant fluid through a reverse Carnot cycle. This is beyond the capability of a home experimenter. Ordinary refrigeration compressors cannot follow the Carnot cycle.



FORBES, MARCH 20, 1978

Follow-through

The Heat Pump Gets Hot

A year ago William L. Sammons, head of Carrier Corp.'s consumer products division, told FORBES (*Mar. 15, 1977*) how his company planned to lessen its dependence on the fiercely competitive air-conditioning business (where it is number one) and turn the energy crisis to profit. Carrier was putting its money on the heat pump, a gadget that pulls heat from the air into a building, or pumps heat out of a structure to cool it. The pumps weren't new but had never quite matched the rosy promises of their early promoters. The Arab oil embargo had propelled Carrier into an all-out effort to sell the pumps primarily because the Syracuse, N.Y. manufacturer was convinced that the electrically driven devices were almost 300% more efficient in using power for heating.

Carrier's Sammons: The heat is on.

Sammons' prophecies have been fulfilled—and then some. Last March he and his competitors were anticipating sales of about 360,000 units for 1977. Heat-pump sales last year topped 450,000, and were close to 500,000 if exports are included.

~~The future looks just as promising.~~ A year ago heat-pump sales for 1980 were projected at 575,000, worth about $1.7 billion, more than double the figure for 1976. The 1980 sales projection for the industry now stands at 750,000 (about 40,000 for commercial heating, the rest for homes). By Sammons' reckoning that would add up to about $2.3 billion, or more than three times the 1976 total. And that is the low end of the projection, according to General Electric, which ranks first in heat pumps, followed by Carrier, Lennox, Westinghouse and Rheem. Don Lynch, the senior vice president who heads up the GE air-conditioning and business division in Louisville, Ky., thinks the 750,000 figure is conservative. Heat-pump sales, he says, could well reach 1 million in 1980.

Why is the heat pump catching on after all these years? Speaking in his corporate role, Sammons credits his "increasingly knowledgeable" dealers and "increasingly sophisticated" consumers.

Putting it in more down-to-earth terms, the Carrier executive says: "It's the daily headlines in newspapers and magazines which say that energy is a problem. This is bound to sink in."

What Counterattack?

Detroit was counterattacking the waves of invading Japanese automobiles, FORBES reported last summer (*July 15, 1977*); by concentrating on the small fuel-saving models that customers seemed to want—and which Washington's energy planners had decreed. U.S. automakers, FORBES concluded, would "within a period of two years check the foreign invasion but never completely turn it back."

That two-year deadline has a way to go, but so far Detroit's battle plan doesn't seem to be working. Auto sales figures for January demonstrated that (and February's are expected to confirm it). While mighty General Motors' sales slipped 12% in January, Japanese imports climbed 26%, the eleventh monthly increase in a row. Only Ford Motor Co. showed an increase over January 1977, a 1% improvement. With Toyota, Honda and Datsun leading the charge, January imports added up to 141,000 cars, or almost 21% of the U.S. market, exactly where they stood last summer.

Those numbers immediately sparked news stories repeating Henry Ford II's offhand remark last year that Detroit would drive the foreigners into the sea (without noting, however, that Ford had prudently set no timetable).

Is Detroit in serious trouble?

Not to the really big wheels in the Motor City. Last month GM Chairman Thomas A. Murphy stuck resolutely to his 1977 forecast of 11.75 million car sales for the current year, though he did concede that his figure was about an octave higher than virtually everyone else's. (Ford, for example, is saying 11.1 million.) Murphy put most of the blame

MI FEB. 1981 Mechanix Illustrated

ARE SOLAR HEAT PUMPS THE FUTURE IN HOME HEAT?

By Philip L. Harrison

IN AN AGE where the price of energy seems to be going through every roof, it's little wonder that homeowners are seeking cheaper ways to keep the home warm. It's little wonder, too, that the heat pump business is getting hotter all the time. Heat pumps, because of their high efficiency over, say, electrical resistance heating, can offer an average saving of 45 percent, depending on where you make your abode.

Solar heating, too, is tempting, but technology has not made it a practical proposition for much of the country. Until now, that is.

Now the race is underway to team the heat pump with solar collectors. The combination could just possibly develop into one of the most efficient home heating systems ever.

A top-of-the-line standard heat pump might have an average COP rating of 2.5, which means that for every BTU of electrical energy going into the unit, you get 2.5 BTUs of heat out.

But there are efficiency problems. As the outside temperature falls, the COP of the heat pump also falls. This is because the evaporator's temperature must always be colder than the outside air. In other words, just when you need it most, the heat pump starts costing more to operate. That's where the solar connection comes in.

The system that is sure to shake up the market a bit is Fedders' *Carnot II Solar Compression Furnace.* Named for French physicist Nicolas Leonard Sadi Carnot, the Carnot II replaces the heat pump's usual reciprocating compressor with a rotary one. The result is an impressive drop in compressor electrical energy consumption.

Solar-heated water in the system is pumped from a storage tank into Carnot II, where it enters a coaxial counterflow evaporator. In this evaporator, warm water flows in one direction through an inner tube while cold Freon vapor circulates through the outer tube in the opposite direction.

Heat is transferred to the Freon, which is then drawn into the rotary compressor and pressurized. The temperature is raised to as much as 175°F. In the condenser, which also has a coaxial counterflow design, the Freon sheds the heat into a closed water circuit serving a fan-forced hydronic heating coil. The resulting warm air is then ducted to the house.

High-cost, high-efficiency solar collectors are not required and, in some areas of the country, could prove to be a detriment with the Carnot II.

Fedders will sell the Carnot II with or without collectors, so if you already have water collectors on your roof, the Carnot II can be retrofitted to them.

What does all this mean in terms of efficiency? An optimum COP of 12, with an average of around 7. You read it right. For every BTU in, you get seven out.

Installations placed in the chilly town of Caribou, Maine, on the Canadian border, rated an average COP of 5.56, which is more than double the average COP of the best standard heat pumps currently available. Albuquerque installations averaged 9.2 and those in Kansas City, 8.8.

Heat Pumps: Off and Running . . . Again

Leon R. Glicksman

Technology Review, June/July, 1978

Heat pumps appear to defy the law of energy conservation by producing thermal output two to three times greater than their mechanical input. But public unfamiliarity and the poor performance of some early models hamper their acceptance.

Fully half of the energy used in the residential and commercial sectors of the U.S. economy goes for space heating: one-sixth of total U.S. energy use, and one-fourth of our total oil and natural gas consumption. The sheer size of this energy demand establishes residential and commercial space heating as a fertile field for new or improved technologies that may increase the efficiency of energy use. The inefficiency of current space conditioning apparatus adds incentive to the effort.

Heat pumps appear to contradict the principle of energy conservation by providing two or more units of thermal energy while using only one unit of electrical energy. The use of heat pumps has been held back in no small measure by skepticism about their performance in apparently defying this scientific principle.

The Coefficient of Performance

The most remarkable property of the heat pump is probably the efficiency with which it uses electricity to achieve the transfer of thermal energy from one volume of air to another. If we call the absolute value of the heat rejected by the refrigerant in the condenser Q_c, the heat absorbed by the refrigerant in the evaporator Q_E, and the electrical energy or work needed for compression W, then a simple energy balance between the energy received and given up by a heat pump during one cycle is:

$$Q_C = Q_E + W.$$

The heat transferred to or from the room air by a heat pump is the useful output of the device, and is always greater than the input of electrical energy W.

A measure of heat pump efficiency can be provided by forming a ratio of the amount of heat rejected by the condenser to the quantity of electrical energy consumed to power the heat pump. This ratio, called the coefficient of performance, or COP, is defined as:

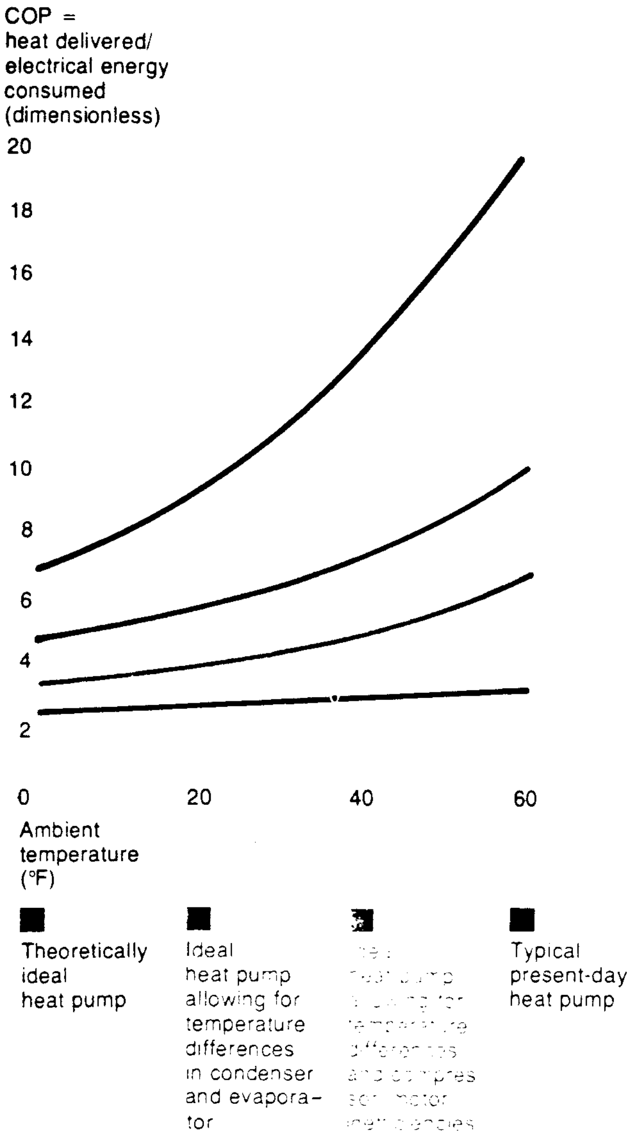
$$\mathrm{COP} = Q_c/W.$$

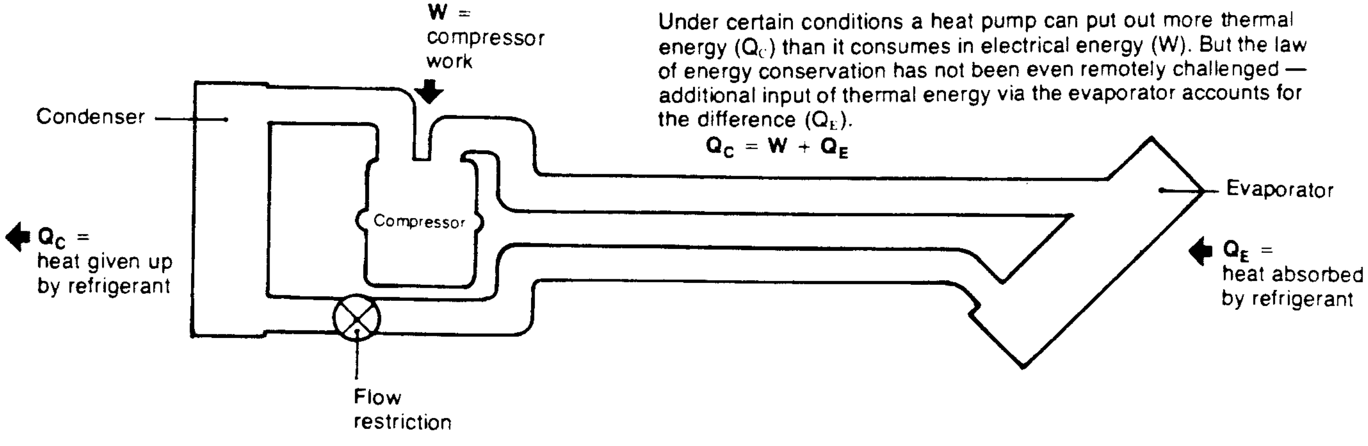
The COP depends on the minimum and maximum refrigerant temperatures experienced in the cycle, where T_{low} and T_{high} are, respectively, these two temperatures expressed in degrees Kelvin or Rankine. The theoretical upper limit of the COP can be expressed as

$$\mathrm{COP}_{\lim} = (1 - T_{low}/T_{high})^{-1}.$$

The actual efficiency of a heat pump is dependent on the climate in which the heat pump is operated. A given heat pump will perform quite differently, for example, in Boston and in Tallahassee. This is because the temperature and pressure of the refrigerant in the heat pump evaporator decrease as the ambient temperature is reduced. The pressure difference between the refrigerant in the evaporator and condenser therefore increases, necessitating additional work to compress the vapor. Increasing work W brings about a decrease in overall COP — and a bigger electricity bill.

Heat pumps with average COPs of 3.0 or greater will use less energy overall than fossil fuel furnaces. Today's units come close to this efficiency under some conditions.





Under certain conditions a heat pump can put out more thermal energy (Q_C) than it consumes in electrical energy (W). But the law of energy conservation has not been even remotely challenged — additional input of thermal energy via the evaporator accounts for the difference (Q_E).

$$Q_C = W + Q_E$$

John F. Sandfort
Doubleday 1962

We have seen that when a reversible process or cycle is operated in reverse order, all external effects are likewise reversed. Thus, if the Carnot engine shown in Fig. 25 is reversed, heat will flow from the low-temperature reservoir and into the high-temperature reservoir, while work is supplied to the engine. But this reversed heat engine is in effect a *heat pump,* a machine capable of "pumping" heat from a cold region to a hot region. Depending on how we applied such a machine, we could produce a refrigeration effect or a heating effect.

Lord Kelvin saw the fundamental similarity of heat engines and heat pumps insofar as they are both thermodynamic machines, and wrote the paper in 1852 entitled, "On the Economy of the Heating or Cooling of Buildings by means of Currents of Air."[8] In this paper Kelvin wrote more like an engineer than a physicist in that he presented the design details of a heat pump. By alternately compressing, cooling, and expanding air in a dual cylinder and piston apparatus, the apparatus could produce either a refrigeration or heating effect. But let us read how Kelvin himself explained it.

> In the mathematical investigation communicated with this paper, it is shown in the first place, according to the general principles of the dynamical theory of heat, that any substance may be heated thirty degrees above the atmospheric temperature by means of a properly contrived machine, driven by an agent (work) spending not more than $1/35$ of energy of the heat thus communicated; and that a corresponding machine, or the same machine worked backwards, may be employed to produce cooling effects, requiring about the same expenditure of energy in working it to cool the same substance through a similar range of temperature. When a body is heated by such means, about $34/35$ of the heat is drawn from surrounding objects and $1/35$ is created by the action of the agent (work); and when a body is cooled by the corresponding process, the whole heat abstracted from it, together with a quantity created by the agent (work), equal to about $1/35$ of this amount, is given out to the surrounding objects.
>
> A very good steam engine converts about $1/10$ of the heat generated in its furnace into mechanical effect; and consequently, if employed to work a machine of the kind described, might raise a substance thirty degrees above the atmospheric temperature by the expenditure of only $10/35$ or $2/7$, that is less than $1/3$ of the coal that would be required to produce the same elevation of temperature with perfect economy in a direct process. If a water-wheel were employed, it would produce by means of the proposed machine the stated elevation of temperature, with the expenditure of $1/35$ of the work, which it would have to spend to produce the same heating effect by friction.
>
> The machine by which such effects are to be produced must have the properties of a perfect thermodynamic engine, and in practice would be either like a steam engine, founded on the evaporation and re-condensation of a liquid (perhaps some liquid of which boiling point is lower than that of water), or an air engine of some kind.

Kelvin went on to calculate specific design data for an air heat pump in which air could be either heated from 50°F. to 80°F. or cooled from 80°F. to 50°F. Again in his own words:

> If it be required to heat the air from 50°F. to 80°F., the ratio of expansion to the whole stroke in the egress cylinder would be $18/100$, the pressure of the air in the receiver would be $82/100$ of that of the atmosphere (about 2.7 lbs on the square inch below the atmospheric pressure), and the ratio of compression to the whole stroke in the egress cylinder would be $15/100$. If 1 lb of air (or about 15½ cu ft at the stated temperature of 80°, and the mean atmospheric pressure) be delivered per second, the motive power required for working the machine would be .283 of the horsepower, were the action perfect, with no loss of effect, by friction, by loss of expansive power due to cooling in the egress cylinder, or otherwise. If each cylinder be four feet in stroke, and 26.3 inches diameter, the pistons would have to be worked at 30 double strokes per minute.

Kelvin's calculations showed that when this machine was operated as an air conditioner, in which 15½ cu ft of air per second were cooled from 80°F. to 50°F., 24.6 double strokes per minute would be required with a consumption of .288 horsepower.

Kelvin's paper may have been inspired by a desire to do something to control the temperature of the air in the British government buildings in India, which were insufferable to Englishmen not accustomed to the climate. As far as we know, his thermodynamic heating and cooling machine was never built, but we do know that it would have worked. Kelvin's device was most remarkable on two counts. First, it anticipated our present air conditioning and heat pump industry by nearly 100 years, and, secondly, it showed the power of the newly emerging science of thermodynamics to predict the performance of a reversed heat engine in an entirely new application, without building the machine and then modifying it after blind groping in trial-and-error procedures.

---

[8] *Glasgow Philosophical Society Proceedings,* Vol. 3, December 1852.

CYCLES AND EFFICIENCY

We have already seen how Lord Kelvin hit on the idea of operating a heat engine in reverse and thus using it as a heat pump. We might assume logically that the maximum theoretical performance of such a machine could also be expressed as a function of temperature, similar to our calculation of maximum heat engine efficiency. Let us see how this can be done.

If the Carnot heat engine is reversed, the heat and work quantities simply reverse their direction, and the cycle traced on the *T-S* diagram now moves in an opposite or counterclockwise direction, Fig. 35. Now work must be put into the heat pump, with the result that heat Q_L will be "pumped" from the low-temperature reservoir, and heat Q_H will be transferred into the high-temperature reservoir. If the effect we are trying to achieve is that of *refrigerating* an area below the temperature of its surroundings, as in a kitchen refrigerator, a cold-storage locker or a room air conditioner, we call the reversed heat engine a refrigeration unit or compressor. In this case the refrigeration effect is represented by the crosshatched area Q_L, and the work required to produce this effect is shown by the crosshatched area *W*, Fig. 35a.

On the other hand, the effect we want may be that of using the reversed heat engine as a *heating* machine. In this case we commonly call the reversed heat engine simply a heat pump, although, in the context of thermodynamics, a heat pump should include *any* reversed heat engine. The heating effect Q_H, now desired, is represented by the total area under path 1–2, and this includes both crosshatched areas in Fig. 35a. The work required remains the same, area *W*.

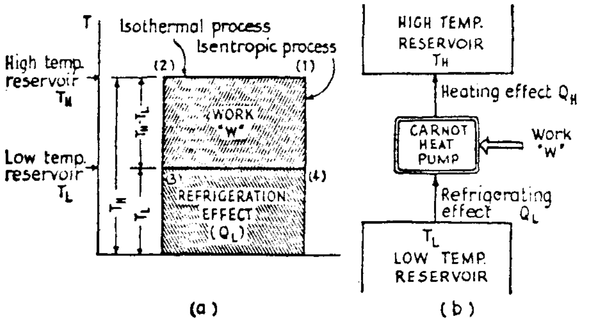

T
Isothermal process
Isentropic process
High temp. reservoir T_H
Low temp. reservoir T_L
(2)
(1)
(3)
(4)
$T_H - T_L$
T_H
T_L
WORK "W"
REFRIGERATION EFFECT (Q_L)
HIGH TEMP. RESERVOIR T_H
Heating effect Q_H
CARNOT HEAT PUMP
Work "W"
Refrigerating effect Q_L
T_L LOW TEMP. RESERVOIR
(a)
(b)

Fig. 35. Carnot *heat pump* cycle on a *T-S* diagram

In the operation of heat engines, we are striving to *convert* heat energy into work, and the degree to which we are successful in doing this we express as thermal efficiency. With refrigeration units and heat pumps, however, we are not striving for a maximum conversion of energy from one form to another. Instead, we are trying only to pump a maximum amount of heat with a minimum amount of work, and the ratio of the effect desired to the work required to produce this effect is designated as coefficient of performance (C.P.). Thus, for a refrigeration unit,

$$C.P._{Ref} = \frac{Q_L}{W} = \frac{T_L}{T_H - T_L} \text{ (Fig. 35a)}$$

and for a heat pump,

$$C.P._{HP} = \frac{Q_H}{W} = \frac{T_H}{T_H - T_L}$$

As an example, suppose we wish to determine the smallest amount of work that would be necessary to operate a deep-freeze unit at 0°F. (460°F. abs.) in a room at 75°F. (535°F. abs.). We can quickly calculate the coefficient of performance:

$$C.P._{Ref} = \frac{T_L}{T_H - T_L} = \frac{460}{75} = 6.13$$

This equation says that for every unit of work energy we put into the compressor, we can *in theory* pump 6.13 equivalent units of heat energy out of the deep freeze.

As another example, suppose we wish to heat our house at 75°F. with a heat pump using the outside air at 0°F. as the heat source. Again calculating the coefficient of performance, we have:

$$C.P._{HP} = \frac{T_H}{T_H - T_L} = \frac{535}{75} = 7.13$$

In words, the theoretical heating effect we can get out of this heat pump is 7.13 times the equivalent units of electrical energy we supply to it to operate the compressor motor. This does not mean, of course, that we are creating energy, but we are in a sense getting something for nothing. To explain, suppose we had 5 kilowatts of electricity available to heat a room. We could use it directly in an electric heater and produce 5 × 3413 or 17,065 Btu per hour.[2] On the other hand, we could use these 5 kilowatts to operate a heat pump motor, and in this case it would be theoretically possible to get 7.13 × 17,065 or about 121,500 Btu per hour heating effect. The gain in Btu might be the difference between heating a single room or an entire house. In this case the energy pumped from the outside air at 0°F. would be free for the taking, but the total energy balance would still be conserved. This can be seen by referring to Fig. 35b. The heating effect Q_H would equal 121,500 Btu per hour, which would be 7.13 times as great as the electrical work input *W*, but the difference between Q_H and *W* would exactly equal the heat Q_L drawn from the 0°F. reservoir.

Remember, though, that these figures represent the maximum conceivable performance of a *perfect* heat pump, in which there is no irreversibility or net entropy increase, a condition that cannot be reached in practice. Actual heat pumps operate at lower coefficients of performance, just as actual heat engines operate at thermal efficiencies below the Carnot value.

---

[2] One kw. = 3413 Btu per hour.

The Vapor Compression Cycle

We have seen that both heat engines and heat pumps[5] developed historically in a similar pattern. Crude machines were built by ingenious men long before the fundamental processes were understood or adequate theories worked out. Even the machinery components were similar in many respects. Both employed cylinders with reciprocating pistons, both circulated thermodynamic fluids such as steam, air, or some special refrigerant, and both required heat transfer equipment such as boilers, condensers, evaporators, and cooling coils.

Then, in the middle of the 19th century, the theoretical foundations were laid for understanding the conditions under which heat could be converted into work and mechanical refrigeration could be produced. Long-standing mysteries were suddenly clarified, and it was discovered that heat engines and heat pumps were essentially the same thing.

Prior to this time two general types of heat pumps had been built in very limited numbers and in a very crude form. One type used air as the thermodynamic medium while the other type used a volatile liquid such as ether. Air cycle heat pumps had one obvious advantage—the refrigerant used was absolutely safe. Obviously, air is nontoxic and non-flammable, and safety was of paramount importance in some types of applications. But thermodynamics later showed that there were some theoretical objections to the air cycle heat pump. Let us see now what these were.

In Fig. 35 we saw how a process of the perfect reversible Carnot heat pump could be represented as a rectangular cycle on a *T-S* diagram. First, heat is taken from a cold reservoir at constant temperature (isothermal process), then the gas or vapor is compressed reversibly and adiabatically (isentropic process) to a higher temperature, next heat is transferred to the high-temperature reservoir, again at constant temperature, and finally the cycle is completed by expanding the thermodynamic fluid reversibly and adiabatically back to its starting point. This, then, is how a *perfect* heat pump can operate, one that will have the maximum conceivable coefficient of performance. Note that there is no limiting condition in the analysis of the Carnot cycle that specifies the type of fluid that must be used. The only condition is that the cycle must be reversible and must consist of two isothermal and two isentropic processes. Thus, either a gas, such as air, or some condensable vapor, such as ether or ammonia, could be used.

In designing an actual refrigeration machine, however, we are faced with the problem of producing a *practical* machine. Just as in the case of heat engines, engineers have concluded through long experience that the most suitable way to build a heat pump for practical applications is as a steady-flow device, in which each process of the cycle is performed in a separate piece of equipment. Thus if air were used as the refrigerant, a logical arrangement of equipment would be as shown in Fig. 41a. Air could be expanded isentropically through an expansion turbine to some lower pressure and temperature, process 1–2. This cold air would then pick up heat (refrigeration effect) by flowing through a coil at constant pressure, process 2–3. Next the air would be compressed isentropically in a turbocompressor to some higher temperature, process 3–4, and finally heat would be removed from the cycle by passing the air through another heat exchanger at constant pressure, process 4–1.

This is certainly a practical cycle, one in which the component parts could be arranged in a suitable form for convenient use. Heat exchangers and turbocompressors can be designed and manufactured without difficulty, and the expansion turbine could help drive the turbocompressor if placed on the same shaft as shown.

But how does this compare with the ideal Carnot heat pump? The comparison can best be shown by drawing the cycle on a *T-S* diagram, Fig. 41b. Both the expansion process, path 1–2, and the compression process, path 3–4, can closely approach the reversible adiabatic (constant entropy) path. In other words, there is no *theoretical* reason that these processes cannot be isentropic, as in the Carnot cycle. However, when heat is added to air at constant pressure, the temperature rises rather sharply. Likewise, when heat is removed, the temperature drops. Therefore, our constant pressure processes 2–3 and 4–1 are *not* isothermal and depart from the ideal Carnot cycle. This, then, must be a compromise between the theoretical advantage of transferring heat isothermally, and the practical simplicity of using a heat

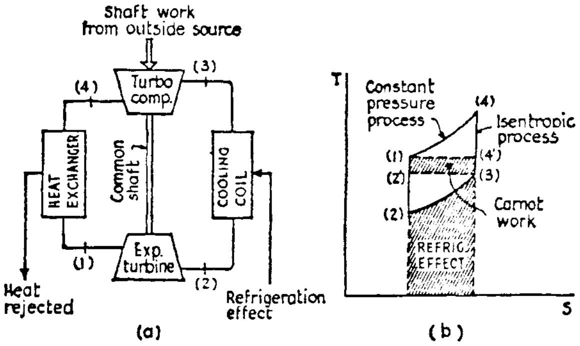


Fig. 41. Air compression refrigeration cycle

exchanger where the air flows through at constant pressure.

---

[5] Heat pumps may be called refrigerators, refrigeration machines or compressors, condensing units, air conditioners, room coolers, or heat pumps, depending on the application. Actually, they are all *heat pumps* in a thermodynamic sense.

But exactly what is the theoretical thermodynamic objection to using the constant pressure rather than the constant temperature processes? We can explain it this way. The air at state (2) must be considerably colder than the refrigerated area that we are serving, while the air at state (4) must be considerably hotter than the cooling water or other reservoir to which we are rejecting heat. This results in thermal irreversibility and a resulting loss in coefficient of performance. This loss can be clearly shown by referring to the *T-S* diagram, Fig. 41b. The refrigeration effect is represented by the crosshatched area under path 2–3, while the net work required is shown by the area enclosed by the cycle 1–2–3–4–1. But a Carnot cycle would be represented by the dotted rectangle 1–2′–3–4′–1, and we can see at a glance that not only would the required work be reduced by the two triangular-shaped areas, but the refrigeration effect would also be increased by the amount of the triangular-shaped figure 2–3–2′.

It was this theoretical limitation, together with some other objections, that accounted for the gradual elimination of the air compression cycle as a serious competitor to the vapor compression cycle many years ago. Let us now see how the vapor cycle of Jacob Perkins ultimately proved to be superior.

From a thermodynamic viewpoint there are two reasons why it is advantageous to use readily condensable vapors as refrigerants. One reason is that these vapors, just like water, change phase[6] at constant *temperature* while heat is added to the saturated liquid at constant pressure, or while heat is removed from the saturated vapor at constant pressure. We can duplicate the isothermal processes of the Carnot cycle while condensing a vapor or boiling a liquid in conventional, steady-flow, constant-pressure heat exchangers. Another reason is that a liquid at high pressure, unlike air, will drop sharply in temperature when throttled to some lower pressure. We can eliminate the expander turbine, which was a necessary and rather expensive component of the air cycle. In its place we can now substitute an inexpensive throttle valve or expansion valve, as it is called in the trade.

A simple flow diagram for the vapor compression cycle is shown in Fig. 42a. And its corresponding cycle on a *T-S* diagram is shown in Fig. 42b. Its sequence of operation is described as follows:

A saturated liquid is first throttled from the high-condenser pressure and temperature to the lower evaporator temperature and pressure as shown by process 1–2. Note that this is a completely irreversible adiabatic process, and so the exact path cannot be shown on a *T-S* diagram. That is why a dotted line connects states (1) and (2) in Fig. 42b. The entropy has increased as shown, but the area under the dotted line has no significance. Note too that the refrigerant has changed from a saturated liquid at state (1) to a mixture at state (2), since a part of the liquid has flashed into a vapor as the temperature dropped.

After leaving the expansion valve, the mixture is piped to an evaporator, where the remaining liquid boils at constant low temperature and pressure[7] until becoming a saturated vapor at state (3). This process produces the refrigeration effect shown by the crosshatched area in Fig. 42b. The saturated vapor is then drawn into a compressor, where it is compressed isentropically along path 3–4. During this process the vapor is superheated, and when it enters the condenser at state (4), it first must be desuperheated until it again becomes a saturated vapor and then is condensed the rest of the way at constant temperature as shown by path 4–1.

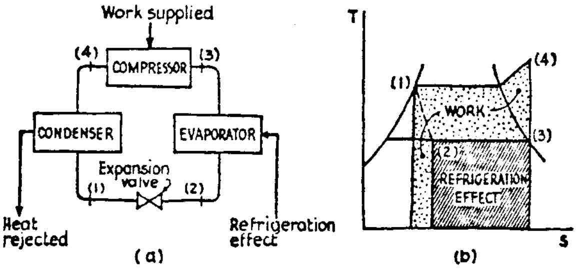


Fig. 42. Vapor compression refrigeration cycle

The entire area under path 4–1 represents heat rejected from the cycle, and therefore the difference between this area and the crosshatched area representing refrigeration effect, represents the work required. We can see from an examination of the *T-S* diagram that this area is still somewhat greater than a corresponding Carnot rectangle would be, but the theoretical advantage over air should be apparent. The coefficient of performance theoretically possible with the vapor compression cycle depends on a number of factors, such as the type of refrigerant used, the amount of superheating that occurs, and the various ways that this elementary cycle can be modified. How successful it has been is evidenced by the fact that today it clearly dominates all the other forms of refrigeration combined.

One of the reasons for this domination was the success in finding better refrigerants. With the rapid expansion of the vapor compression refrigeration industry, much research effort was directed toward this end. Ether was highly inflammable; carbon dioxide required extremely high condensing pressures; ammonia was widely used for many years and had many favorable thermodynamic characteristics but was highly toxic and also inflammable under certain conditions; sulfur dioxide was used to some extent, but it was toxic and highly corrosive in the presence of moisture.

---

[6] This is a term used to describe the change of a saturated liquid to a saturated vapor or vice versa.

[7] For example, liquid ammonia boils at –28°F. when at atmospheric pressure, and ammonia vapor condenses at 80°F. when at 153 lbs per sq in. absolute.

It was not until 1930 that Dr. Thomas Midgley announced to the scientific world the discovery of a group of chemical compounds called halogenated hydrocarbons,[8] which not only had the necessary thermodynamic and chemical properties to make them desirable refrigerants, but also were non-toxic and non-flammable. This development gave the refrigeration and air conditioning industries a tremendous boost as it permitted the use of vapor compression equipment in homes and public buildings, with perfect safety. Because these refrigerants are so safe, they have found wide use in the so-called "aerosol bombs" which are now used to dispense hundreds of products, from insecticides to tooth paste.

So much for our brief study of the thermodynamic foundation of heat engines and heat pumps. But before we close our story let us see what progress has been made in heat engine development during the past century, and after the period of Carnot, Kelvin, and Clausius. What has the development been in areas other than steam and what is the outlook for the years to come?

---

[8] More popularly known under the trade names of Freon, Genetron, etc.

Loss of Ozone Could Doom World Soon, Scientists Say

Washington

A dramatic loss of ozone over Antarctica proves the greenhouse effect is real and presages a gradual warming of the Earth that threatens floods, drought, human misery in a few years and — if not checked — eventual extinction of the human species, scientists warned yesterday.

"I believe global warming is inevitable; it's only a question of magnitude and time," Robert Watson told the Senate Environment Subcommittee on Environmental Pollution.

"We can expect significant changes in climate in the next few decades," said Watson, predicting that if nothing is done to slow ozone-depleting air pollution, temperatures around the world could rise as much as 10 degrees.

Watson is director of the upper atmospheric program for the National Aeronautics and Space Administration.

James Hansen, director of NASA's Goddard Institute for Space Studies, said that global temperatures should be nearly two degrees higher in 20 years, "which is about the warmest the Earth has been in the last 100,000 years."

Sherwood Rowland, a University of California chemistry professor, said, "If you have the greenhouse effect going on indefinitely, then you have a temperature rise that will extinct human life" in 500 to 1000 years.

The warnings came as the subcommittee opened two days of hearings on the greenhouse

Back Page Col. 1

effect — a long-forecast consequence of man's pumping into the atmosphere such chemicals as chlorofluorocarbons, carbon dioxide, methane and nitrous oxide.

Scientists say that by accumulating in the atmosphere and destroying the vital ozone layer, these and other substances trap heat in the atmosphere, producing droughts in some places and causing coastal areas to be inundated by oceans swollen by melting polar and glacial ice.

For humans, they predict increases in skin cancer as the Earth's surface is bombarded by increasingly greater amounts of ultraviolet rays that are normally screened to relatively safe levels by the ozone belt.

The pace of atmospheric destruction is increasing steadily and rapidly, said Rowland, who in 1974 published pioneering research on chlorofluocarbons — gases used as refrigerants and aerosol-can propellants.

This led the United States to ban their use in spray cans, but it continues elsewhere.

"There is now compelling observational evidence that the chemical composition of the atmosphere is changing at a rapid rate on a global scale," Watson said.

The scientists, calling for curbs on air pollution, said a recently completed five-year study in Antarctica provides an ominous signal to the world. They said that during that period, there was an ozone loss over the South Pole of from 30 percent to 50 percent.

Rowland said the finding proved "the remarkable corelation between this depletion in the Antarctic ozone and the rapid growth in the atmospheric concentrations of chlorofluoromethanes, and the connection is inescapable."

"We now have a hole in the ozone layer which will last for a century or more, even if the entire world were to stop further emissions of chlorofluorocarbons today — which is of course impossible," Rowland said.

The "hole" Rowland referred to is not literally present year-round, but appears every October.

Watson said scientists have calculated that if no action is taken to curb chemical emissions, "the greenhouse warming predicted to occur during the next 50 years should be about twice that which has occurred during the previous 130 years."

Hansen said the average U.S. temperature has risen from one to two degrees since 1958 and is predicted to increase an additional three or four degrees between 2010 and 2020.

He said that with an expected doubling of atmospheric carbon dioxide by 2040, the number of days each year with temperatures over 80 degrees would rise from 35 to 85 in Washington, D.C., and Omaha, Neb.

Stephen Leatherman of the University of Maryland said that during the last 100 years the sea level has risen about one foot, with about half the increase attributed to global climate warming.

A one-foot rise, he said, generally will produce 100 feet of shoreline erosion on the Atlantic and Gulf coasts. "Within the next 40 to 50 years, sea level will probably have risen by a foot, resulting in major impacts to coastal environments," he said.

Under this projection, the resort town of Ocean City, Md., will lose 39 feet of shoreline by 2000 and a total of 85 feet within the next 25 years, according to Leatherman.

Associated Press

Omni
May 1987

OZONE-FRIENDLY REFRIGERATOR

A New Jersey manufacturer of Space Age refrigeration equipment has borrowed from nineteenth-century technology to make a small refrigerator (motor shown at right) that runs on inert helium or nitrogen instead of Freon, and uses 50 percent less energy than conventional refrigerators do.

The chlorofluorocarbons produced by most home refrigerators are blamed for depleting the earth's protective ozone layer. Not so with the equipment made by Cryodynamics, Inc., claims Stephen F. Malaker, the company president.

His refrigerator has a capacity of 5.3 to 7 cubic feet, compared with the 18 to 21 cubic feet of the average American refrigerator today. "We're working with the Chinese government to make nine million of them a year by 1990. They'd be perfect there. Chinese apartments are very small," says Malaker, whose machines will sell for about $200—a princely sum, considering the average worker in Shanghai makes only about $27 a week. The Cryodynamics models could hit the American market in late 1988 and will sell for the same price, says Malaker.

—George Nobbe

Access: Stephen F. Malaker, Cryodynamics, Inc., 191 Mill Lane, Mountainside, NJ 17092.